V. *The Rubies of Burma and Associated Minerals: their Mode of Occurrence, Origin, and Metamorphoses. A Contribution to the History of Corundum.*

By C. Barrington Brown, *Esq., Assoc. R.S.M., F.G.S., and Professor* John W. Judd, *C.B., LL.D., F.R.S., F.G.S.*

Received February 6,—Read March 7, 1895.

[Plate 6.]

Contents.

I. Introduction.

In the year 1798 Greville established and named the mineral species "corundum," the crystallized oxide of aluminium; and in an appendix to Greville's paper, read before this Society,* the Count DE BOURNON correctly defined the crystallographic characters of the species. Four years later the last-mentioned author laid before the Royal Society his very valuable memoir, bearing the title, "Description of the Corundum Stone and its Varieties, commonly known by the names of Oriental Ruby, Sapphire, &c., with Observations on some other Mineral Substances."† In this work the mode of occurrence of corundum is discussed, and an admirable account is given of the minerals with which it is associated in the famous gem-yielding localities of Ceylon, China, and Southern India. In all of these districts DE BOURNON showed that the corundum occurs in crystalline schists; being associated in the Salem district of the Madras Presidency with moonstone, anorthite, fibrolite, diaspore, hornblende, quartz, mica, talc, garnet, zircon, and magnetite; while in Ceylon its chief associates are spinel, pyrrhotite, tourmaline, ceylanite (pleonast), and zircon. DE BOURNON'S memoir is especially noteworthy as containing the first descriptions of two very important rock-forming minerals—anorthite ("indianite") and sillimanite ("fibrolite").

Nearly twenty years later, LESCHENAULT DE LA TOUR was sent by the authorities of the Natural-History Museum of Paris on a scientific mission to the Salem district in Southern India, and an account of his observations—botanical, zoological, and geological—appeared in the official publications of the Museum.‡ LESCHENAULT'S collections are preserved in the Muséum d'Histoire Naturelle, and those of the Count DE BOURNON in the Collège de France, and both these collections have been made the object of a series of careful and exact studies by the able mineralogist and petrographer M. ALFRED LACROIX.§

Since the time of DE BOURNON and LESCHENAULT DE LA TOUR, some further accounts of the gem-bearing rocks of the Salem district in Madras have been published by NEWBOLD,|| J. CAMPBELL,¶ and E. BALFOUR,** while Dr. KING and Mr. W. BRUCE FOOT have described the general geological features of the whole district in their memoir "On the Geological Structure of Portions of the Districts of Trichinopoly, Salem, and South Arcot, Madras,"†† and a summary of the results of the work of the Geological Survey of India in this district is given in the first edition of the 'Manual of the Geology of India,' by Messrs. H. B. MEDLICOTT and

* "On the Corundum Stone from Asia," by the Rt. Hon. CHARLES GREVILLE, 'Phil. Trans.,' vol. 88 (1798), pp. 403–448.

† *Ibid.*, vol. 92 (1802), pp. 233–326.

‡ 'Mém. du Muséum d'Hist. Natur. de Paris,' vol. 6 (1820), pp. 329–348; vol. 8 (1822), pp. 245–278.

§ Bull. de la Soc. Fr. Min.' (1889), pp. 282–348; see also 'Rec. Geol. Surv. of India,' vol. 24, Part III., p. 155.

|| 'Asiat. Soc. Journ.,' vol. 7 (1843), pp. 150–171 and 203, 204.

¶ 'Calcutta Journ. Nat. Hist.,' vol. 2 (1842), p. 281.

** 'Select. Rec. Govt. Madras,' vol. 39 (1857), p. 91.

†† Memoirs of the Geological Survey of India,' vol. 4 (1864).

W. T. BLANFORD,* and the second edition of the same work by Mr. R. D. OLDHAM.† Interesting notes on this district are also to be found in Dr. V. BALL's volume on 'The Economic Geology of India' (1881), and in Mr. F. R. MALLET's work on 'The Mineralogy of India' (1887).

Concerning the remarkably similar rocks of Ceylon, there seems to have been very little published in the interval between the appearance of the memoir of DE BOURNON (1802) and that of LACROIX (1889).

Since the period, however, when DE BOURNON's valuable memoir first made geologists and mineralogists familiar with the corundum localities of Salem and Ceylon, a number of works have been published, dealing with the general question of the mode of occurrence of corundum and its associated minerals in other areas. In the Indian peninsula various authors have described the occurrence of corundum in Mysore, North Arcot, Travancore, Coimbatore, Hyderabad, the Central Provinces, Singbuhm, Monghyr, South Rewah, and the Khasi Hills. In South Rewah Mr. F. R. MALLET has given an account of a bed of corundum rock, in places at least thirty yards in thickness, intercalated with the gneiss series of the district.‡ The purplish, granular corundum rock of this locality is described as being associated with diaspore, fibrolite (?), paragonite (euphyllite), and tourmaline (schorl); and the mass is said to be interfoliated with tremolite-schist, amphibolite, and white and green jade—the latter coloured with chromium compounds.

Next in importance to the corundum deposits of the Indian peninsula are the great belts of corundiferous rocks of the eastern United States. These extend along the line of the Appalachian Mountains from Chester in Massachusets to Northern Georgia and have been well described by many authors, among whom may be especially mentioned JOHN DICKSON,§ Dr. CHARLES JACKSON,|| Professor SHEPARD,¶ and Colonel JENKS;** while Mr. T. M. CHATARD, of the U.S. Geological Survey, has given an admirable account of the chief localities and geological relations of the gem-bearing rocks.†† Along this line of country the corundum, occurring either alone or mixed with magnetite (emery), is found in veins of chloritic and vermiculite minerals (ripidolite, jefferisite, &c.), traversing dykes of chromiferous serpentine, which cut through the granites and crystalline schists of the mountain axis. The chief minerals associated with the corundum along this line of country are sillimanite (fibrolite), hercynite, cyanite, smaragdite, zircon, lazurite, rutile, pyrophyllite, and damourite.

* *Loc. cit.*, p. 26.

† *Loc. cit.*, pp. 38, 39.

‡ 'Records Geol. Surv. of India,' vol. 5, p. 20; *ibid.*, vol. 6, p. 43.

§ 'Am. Journ. Sc.,' vol. 3 (1819), p. 4.

|| *Ibid.*, vol. 39 (1865), p. 65.

¶ *Ibid.*, vol. 40 (1865), p. 112; vol. 42 (1866), p. 42; vol. 64 (1868), p. 256.

** 'Quart. Journ. Geol. Soc.,' vol. 30 (1874), p. 303.

†† 'Mineral Resources of the United States' (1883-4), p. 714, &c.

In the district of Mramorsk, near Ekaterinburg, in the Ural Mountains, corundum and emery are described by GUSTAV ROSE as occurring in serpentine and chlorite-schist in association with diaspore and zoisite.* In the Ilmen Mountains, not far from Miask, and in the gold-washings north-east of Zlatousk, KOKSCHAROW has described corundum as being found embedded in anorthite ("barsowite").†

A very valuable contribution to our knowledge of the mode of occurrence of, and the minerals associated with, corundum is contained in the series of papers by Dr. J. LAWRENCE SMITH on the emery formation of Asia Minor.‡ This author shows that the emery of the district in question is a blue corundum, mixed with magnetite, and that it is found, often in masses of considerable size, distributed through a crystalline limestone, which is interfoliated with schists and gneisses. The minerals which accompany the emery, or impure corundum, are diaspore (common), hydrargillite (rare), zinc-spinel (gahnite), pholerite, margarite, muscovite, chloritoid, schorl, chlorite, magnetite, hematite, limonite, pyrite, rutile, ilmenite, and titanoferrite. The localities at which the emery occurs are Gumuch-dagh, Kulah, Adula, and Mauser in Asia Minor, and the neighbouring islands of Naxos, Samos, and Nicaria, in the Grecian Archipelago. More recently, TSCHERMAK has given a fuller account of the emery of Asia Minor, and has shown what an important constituent of this rock is the mineral tourmaline.§

Corundum, in smaller quantities, is known to occur as a constituent of granite and gneiss in the Riesengebirge, Silesia, Auvergne, &c.; in a compact felspar rock, at Mozzo, in Piedmont; in dolomite, with tourmaline, at St. Gothard; while at Orange County, N.Y., and Sussex County, N.J., and other places, corundum has been found with a great variety of minerals in a crystalline limestone.

Corundum has also been detected in masses of gneiss, &c., ejected from volcanoes, as at Königswinter and Niedermendig, &c., and more rarely in the zones formed by contact metamorphism. It has also been detected in the metallic iron of terrestrial origin from Ovifak, Greenland.

It is not necessary to discuss in this place the numerous occurrences of the mineral in its various forms, in river gravels and alluvia, and the various washings from which gold, platinum, and diamonds are obtained.

Upper Burma has long been known to be the source of the magnificent red corundum ("pigeon's blood ruby"), and also of the red spinels (Balas ruby), and of the pink tourmaline (rubellite), a gem which, by the Chinese, is prized even more highly than the true ruby. By Europeans the true, or oriental ruby, is regarded as not only more

* 'Mineralogisch-geognostische Reise nach dem Ural, dem Altai und dem Kaspischen Meere' (1837 to 1842).

† 'Materialien zur Mineralogie Russlands,' vol. 1, p. 30; vol. 2, p. 80.

‡ 'Am. Journ. Sc.,' 2nd series, vol. 7 (1849), p. 283; vol. 9 (1850), p. 289; vol. 10 (1850), p. 354; and vol. 11 (1851), p. 53.

§ "Ueber den Smirgel von Naxos," von G. TSCHERMAK, 'Min. u. Pet. Mitth.,' Bd. 14 (1894), p. 311.

precious than any of the accompanying minerals, but as the most valuable of all gems, and the best coloured varieties fetch far higher prices per carat than diamonds of the finest water.

As might have been expected, however, but very little was known concerning the mode of occurrence of the corundum, spinel, and tourmaline in Burma before that country became a part of the British Empire in 1886. It is probable that all the fine red corundums which found their way into the markets of India originally came from this district, for the Burma mines appear to have been worked from very early times. It is said that the Burmese acquired the mines from the Shans about 1630, but they were regarded as royal property, and very jealously guarded from Europeans.

The existence of the ruby mines of Burma is referred to by many old writers like VINCENT LE BLANC and TAVERNIER. The "Capelan Mountains," mentioned by TAVERNIER* and others as the locality from which the Burmese rubies were derived, appear to be the high grounds around Kyatpyen and Mogok. Some interesting details about the district were collected by JOHN CRAWFORD,† and later by Dr. T. OLDHAM,‡ and further information was given by the Rev. F. MASON (as the result of enquiries made by Captain G. A. STROVER, of Mr. BREDEMEYER§), while Dr. R. ROMANIS and Major HOBDAY (who made the map of the district) were also able to supply Mr. MALLET with some interesting particulars before 1886.||

Very few Europeans are known to have actually visited the ruby mines before the country was annexed by the Indian Government. A runaway English sailor was, in 1830, sent up to blast the rocks by King PHAGYIDORA, but he seems never to have returned. Some time before 1833, the Père GIUSEPPE D'AMATO visited the mines, and published an account of the native methods of working.¶ It is said, too, that in the year 1881, a party of Frenchmen were working at the mines under an engineer in the king's service. About the year 1870 a German mining engineer, named BREDEMEYER, was actually in charge of the ruby mines near Sagyin, twenty-four miles north of Mandalay; but there is no evidence that he was ever permitted to visit the principal mines about Mogok.

When the country was conquered, a map on the scale of four inches to the mile was made under Major J. R. HOBDAY, a first edition of it being published in November, 1886; and in the following month a military expedition to the district was accompanied by Mr. G. S. STREETER, Mr. BILL, and Mr. BEECH, acting on behalf

* TAVERNIER, 'Travels in India,' 1684, p. 143.

† 'Geol. Soc. Trans.,' 2nd series, vol. 1, 1824, pp. 406–408; 'Edinb. New Phil. Journ.,' 1827, p. 366; and 'Journal of an Embassy to the Court of Ava,' 1834.

‡ Appendix to YULE'S 'Mission to the Court of Ava,' 1858, p. 347.

§ 'Natural Productions of Burma,' 1850, p. 27; and 'Notes on British Burma,' 1852; see also 'Indian Economist,' vol. 5, p. 14.

|| 'A Manual of the Geology of India,' Part IV., "Mineralogy," 1887, pp. 42–44.

¶ 'Journ. As. Soc. Bengal,' vol. 2, 1833, p. 75.

of parties who desired to obtain a concession of the ruby mines from the British Government.*

In the following year the Secretary of State for India determined to send out an agent to make independent enquiries concerning the value of the mines, and the conditions under which it would be advisable to permit of their being worked. Mr. C. BARRINGTON BROWN was selected for this task, and every facility was given to him by the civil and military authorities of the country for carrying on his researches. The Secretary of State for India also directed that the specimens collected during this expedition should be sent to the Royal College of Science, with the understanding that, after being studied and described, they should be deposited in the British Museum, and in the Museum of Practical Geology, Jermyn Street.

Mr. C. BARRINGTON BROWN's report on the Ruby Mines of Burma was forwarded to the Indian Government, June 15th, 1888; the fuller account of the geology of the country being deferred till the large and interesting collection of rocks and minerals brought from Burma could be examined and described.

Subsequently to Mr. BARRINGTON BROWN's return two interesting notes have been published by Dr. FRITZ NOETLING, Palæontologist to the Geological Survey of India; one a "Report on the Namseka Ruby Mine in the Mainglôn State (Northern Shan States)," and the other a "Report on the Tourmaline Mines near Mainglôn." These mines are both situated in the district closely adjoining the ruby district of Burma.†

In 1889, also, Mr. T. LA TOUCHE, of the Geological Survey of India, gave an account of the sapphire mines in the Zanskar Valley, in Kashmir, where the blue corundum occurs in gneiss, apparently very similar to that of Burma, the minerals associated with it being anthophyllite (kupfferite), tourmaline, and its alteration product cookeite, spodumene, and lazurite.‡

In the following memoir each section is initialled by the author who is responsible for its contents. J. W. J.

II. GEOGRAPHICAL DISTRIBUTION OF THE RUBY-BEARING ROCKS IN UPPER BURMA.

Extending from Wapudoung village, 11 miles east of the military post of Thebayetkin, to the Shan town of Momeit, in an east-north-east direction, is a wide belt of mountainous country, composed of gneissic rocks, containing along its central portion massive beds of crystalline limestone. The breadth of this tract is about 12 miles, in its widest part; and it has a length of 26 miles. It is situated at a distance of 90 miles to the north-north-east of Mandalay. The rocks forming this mountainous district, especially in the central part of its eastern extension, are ruby

* 'Journ. Soc. of Arts,' Feb. 22, 1889; "Precious Stones and Gems," STREETER, 5th edition, 1892, p. 165.

† Dr. NOETLING's reports are dated 13th November, 1890.

‡ 'Records of the Geological Survey of India,' vol. 23, Part II., pp. 59–69.

bearing; for along this line are situated the principal mines where that gem is found—either in the hill-wash on the mountain sides and gullies, in the cavities of the crystalline limestone, and in the limestone itself, and in the alluvia of the rivers and streams. In all likelihood the ruby-bearing rocks extend further to the eastward; but this region was not examined, owing to its lying outside of British territory, and being consequently a dangerous one to traverse. Although the distance from Thebayetkin to Mogok—the principal mining centre—in a straight line is not more than 34 miles, the distance by road, owing to its tortuous course up and down the mountain sides, is 58 miles. Part of this distance, as far as Kabein, is along a graded government road, while beyond to Mogok the remainder is over a straighter but more precipitous Burman pathway.

From Mogok to the southward for some 15 miles the mountains of gneissic rocks gradually become less in height down to the valley of a large stream called Mobay-choung, which has deposited a wide spread of alluvial clays and gravels. The latter are extensively worked for rubellite by the natives, who say that no rubies are ever found in them. Near this the rocks are of a different character, and are either, so far as seen, mica schists, or a passage rock between schist and gneiss.

The area of the ruby-bearing tract proper, as computed by Mr. PENROSE, of the Government Survey of India, under the direction of Major HOBDAY, in 1888, is estimated at 45 square miles in extent; but, taking in the outlying districts, where old excavations were observed, he was of the opinion that this estimate should be increased to 66 square miles. In this latter area there is little doubt that he has included the rubellite mines of Nyoungouk.

There is a small outlying tract of ruby-bearing rocks at Sagyin, 24 miles north of Mandalay and 8 miles from Maddeya, composed of crystalline limestone, forming low hills, rising from the alluvial plain of the Irrawaddy.

Some 15 miles to the northward of Sagyin are two isolated limestone hills, named Nyoungwun and Bodaw, where it is reported by the natives that rubies have been found.

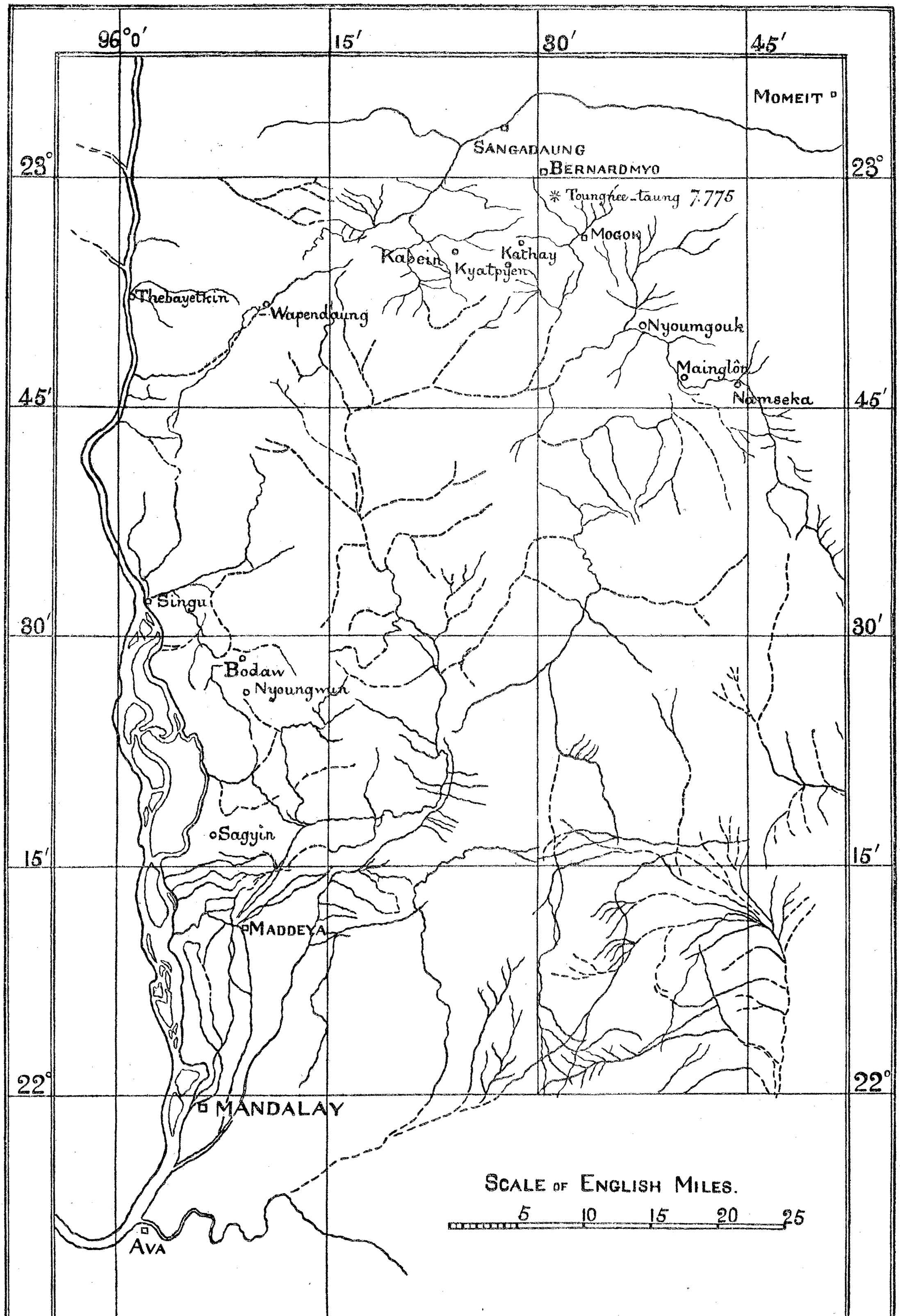
It has been stated that, in making the railway from Rangoon to Mandalay, at Kyoukse, 30 miles from the latter place, an old working in limestone for rubies was discovered.

The ruby-bearing rocks evidently extend over a large portion of Upper Burma on the eastern side of the Irrawaddy, and from thence into the Shan States.

The sketch-map (fig. 1), illustrating the distribution of the gem-bearing localities of this part of Burma, has been compiled from the official map by Major HOBDAY and his assistants on the Topographical Survey of India.

Before proceeding with the main portions of this paper, it is both a pleasure to me, and my duty also, to state that my investigations of the Burma Ruby Mines, described herein, could not have been completed in the time they were, had it not been for the invaluable assistance I received from the following gentlemen, viz.:—

Fig. 1.



Sketch-map of the country north of Mandalay and east of the River Irrawaddy, showing the relative positions of the gem-yielding localities of Burma.

Mr. G. D. BURGESS, Commissioner of the Northern Division of Burma, whom I accompanied from Mandalay to the mines; the late Mr. FFORD, Deputy Commissioner of the Mines Tract; Mr. J. P. CAREY; Mr. E. BUCHANAN, of the Forest Department; Mr. PENROSE, of the Survey of India, who provided me with working maps of the district, &c., and Major HOBDAY, of the same service, who had me supplied subsequently with a complete set of maps; Mr. BENNETT, the Inspector of Post Offices of Northern Burma; MOUNG KYAW KHINE, the Treasury Officer at Mogok; and Lieutenant ANDERSON, who commanded the Military Police; Mr. FOWLE, the Sub-divisional Officer of the Sagyn District; and also Mr. THIRKELL WHITE, who, on my return to Mandalay, was Acting Commissioner for the time being.

Subsequently, at Simla, when I reported to His Excellency, the Viceroy of India, the Earl of AVA, I was received with great kindness, and was much indebted to Sir EDWARD BUCK and Mr. W. N. LAWRENCE, of the Revenue Department, for assistance and kind attention. C. B. B.

III. PHYSICAL FEATURES OF THE RUBY MINES DISTRICT.

From Thebayetkin on the Irrawaddy river, 600 feet above the sea, the starting point for the ruby mines, the country is composed of a hilly tract which increases gradually in altitude until Wapudoung is reached at a height of 1700 feet. Then commences the great group of mountain ranges of that region, trending irregularly in an easterly direction to Mogok, and extending for a considerable distance in the Shan State of Momeit beyond. From the great main ranges, long spurs descend more or less steeply to the plain of the Irrawaddy on the north, and to the hilly grounds and valley of the Mobaychoung on the south. Amongst these mountains are numerous streams which have cut out gorges and valleys in various directions.

The greatest elevation of the mass to the westward of the Kin-choung river, which flows past Kinua (Kinyua)* at 2200 feet above sea level, is about 3500 feet, while, to the eastward, in the neighbourhood of Mogok, the highest points it attains are at Toungnee-taung (Taungmé) and Cheni-taung, which are respectively 7775 feet and 7362 feet above sea level.

From the Irrawaddy to the head of the Kyatpyen (Kyaukpin-meu-ma) all the country is covered with forest, but eastward of that point the extensive valleys of Kyatpyen, Kathay (Kathé), Mogok, and Injauk (Ingyauk), and a great portion of the mountain sides bordering them, are clothed with grass, dotted here and there with small trees and shrubs, with groves in places.

The principal rivers and streams traversing these mountains are the Mogok-choung, with its affluents the Yense and Yaboo; the Avoo; Kyoukwa; Nammi; Injauk; and the Kinchoung.

The Mogok-choung flows in a southerly direction for a considerable distance and

* Thus on map of India Survey.

empties itself into the Mobay-choung; while the Avoo, flowing past Kathay, is joined by the Naghu, from Kyatpyen, further on, and runs into the Mogok-choung some four miles south of Mogok. Rising some seven miles south of Kinua, the Kin-choung flows northward, being joined by the Injauk near Sagadaung, and probably falls into the Shwali river. The Nammi, rising near Chenitaung, runs a south-westerly course to the Mobay-choung.

At Kauklabin there is a fine stream bordered by a level alluvial patch; while in the valley of the Kin-choung, at Kinua, there is a large stretch of alluvial land. The most picturesque and interesting of the valleys, where wide stretches of river deposits form flat level tracts, bounded on all sides by mountains, are those of Mogok, Kathay, and Kyatpyen. Mogok-valley bottom is at a level of 4100 feet above the sea, and lies in a north-east and south-west direction from the village at the lower end to the foot of the mountains below Chenitaung at the upper, having a length of two miles. It is bounded on the north by spurs from the mountains on that side, and on the south by long slopes of the mountain range from Chenitaung through Zelatneetaung to Panma-ywa; while on the west are irregular masses of hills, continuing westward to Kathay, through which runs the Yeboo river in a narrow valley. Amongst these hills are a number of small alluvial flats, through which course small streams. Kyatpyen valley is 4700 feet above the sea, and that of Kathay is 4800.

Northward of Yeboo village lie the mountainous slopes of the Toungneetaung range, which forms the northern watershed of the mass. This great range sweeps from Toungnee peak in a south-westerly direction and, passing through Sagiwa peak, decreases considerably in altitude at Bolongyi; then curving through Welloo it forms the western termination of Kyatpyen valley. The southern side of this latter valley, and of Kathay, consists of low rounded ridges. From Welloo the mountains slope precipitously for 1500 feet to the valley of Kabein. Injauk valley, on the northern side of Toungnee range, is a comparatively small tract of open rolling land, traversed by a fine stream, and bounded on the south and west by the above range, and by low hills on the north and east. From the crests of these the slopes north and west fall steeply down to the plain of the Shwali river, which is continuous with that of the Irrawaddy. The upper portions of the Taungnee range are clothed with forests, which extend down its northern slopes between Injauk valley and Welloo. To the southward of Mogok, to within a few miles of Lauzee and Nyoungouk, the country is likewise well wooded.

There are many fine views and bold scenic effects amongst these mountains and valleys. Perhaps the most curious of all is the view from Mogok village looking up the valley, where the flat extent of land bordering the river narrows inwards to the foot of the mountains in a triangular form, with the picturesque village of Petswe and its quaint pagodas in the distance, and the lofty Chenitaung as a background. On the mountain sides bounding it the colouring lent by the patches of dark green scattered trees and small groves, the light yellowish tints of the dry grass, and the red, pink, and white patches of soil exposed by landslips, is very pleasing. The numerous *twinlone* mines (see p. 184) in operation on the flat with their tall yellow bamboo balance poles, form a striking feature and give an air of activity to the scene.

C. B. B.

IV. Geological Structure of the District (see Map, p. 183.)

1. *Hill Wash.*

As a result of the action of rain and atmosphere, continued through an immense period of time, portions of the rocks of the country, composed mainly of gneiss, have been completely decomposed to greater or lesser depths, and the interbedded crystalline limestone dissolved to a considerable extent, setting free the insoluble constituents. The resulting materials have been washed down the mountain sides, where they now form thick, flanking masses of loamy clays of various colours, from dark red through light red to pinkish, brown, yellow, and white, together with the harder constituents of the disintegrated rocks. During this process a rude sorting of their component parts has been effected, the sands and gravels being collected together and deposited in irregular layers near the base of the clays. The minerals these rocks contained have thus been liberated and deposited amongst the sands and gravels, where old mountain streams have placed them, amongst huge hard water-worn blocks of rock which have been detached from their original positions and rolled down. Owing to the sorting process, the ruby-bearing earthy clays and sands are found in leads at various levels up the beds of steep gullies and in the red clay hill spurs bordering them. They are invariably in irregular sloping patches, one overlapping the other. Where the sands and gravels are mixed with a dark brownish earthy clay, resulting from the disintegration of the crystalline limestone, they are richer in gems such as the ruby and spinel; and these are more frequently found on the eroded surface of the limestone beds themselves.

This superficial deposit covers large portions of the mountainous tract described; but it is only in certain localities where it is worked for the gems it contains. Owing to the mines in this deposit being large open cuttings, called by the natives Hmyaudwins, they afford fair sections disclosing its nature. In order to show this more clearly, a few of these sections will now be described.

The face of the cutting of No. 11 mine, some 20 feet in depth, is composed of reddish loamy clay, completely covering the pinnacled and eroded surface of layers of crystalline limestone. In the lowest portion of this, amongst the large cavities, is a brown earthy clay, mixed with very slightly waterworn pebbles and sand, which contains minerals, including rubies. Embedded in the deposit amongst rounded gneiss boulders is one block of hornblendic gneiss. This section is an interesting one, as showing how completely the limestone outcrop is hidden from view by the hill wash covering.

At No. 10 mine, near Dattau, in the ruby-bearing clay of a yellowish-brown colour, some of the pebbles are rounded, while others are angular. They consist of quartz and pegmatite, and lie at the base of the red hill wash. Amongst the minerals are flat plates of graphite, and in the clays above are large, clear mica crystals scattered through it.

The length of the cutting at No. 1 mine, which is close to Mogok Stockade, is some 400 yards. The height and width of the face is 60 feet, composed of red loamy clay in its upper part passing downward into a brownish clay containing sand and gravel, in which are rubies, and a few sapphires, and other minerals. This rests on the serrated surface of the white and bluish highly crystalline limestone. In the brownish clay are small blocks of semi-decomposed pegmatite.

On the south side of Mogok valley near Petswe is mine No. 9, the only one in operation on that side of the valley in 1888. It is a very extensive working in red loamy clay, having a depth of 28 feet at the face, containing mingled masses of waterworn blocks of pegmatite, ranging from small sizes up to 3 feet in diameter. These rocks contain garnets, and greatly resemble some portions of the crystalline limestone in outward appearance. The ruby-bearing clay at the base of the cutting is of a yellowish and brownish colour, and contains small blocks of semi-decomposed pegmatite.

No. 13 mine is situated on the north side of the Yeboo (Yebu) at the base of the red hill wash, which is there in its lowest part mingled with great blocks and boulders of gneiss and granulite, the latter being of a coarsely crystalline structure, and of great size, some measuring as much as 20 feet in diameter. The gem-bearing portion consists of white waterworn quartz, gravel, and sand, and is deposited amongst and beneath the boulders on the uneven surface of coarsely crystalline limestone. Opposite Kyatpyen, in mine No. 25, this deposit is composed of dark and light red-coloured loamy clay, amongst which are large waterworn blocks of gneiss and pegmatite. The face of the cutting is 30 feet high, and a pit has been sunk to a depth of 40 feet, in order to cut other layers of gem-bearing material, without apparently reaching the bed rock. This shows the great thickness of the deposit in this spot. Amongst the boulders, at the bottom of the cutting, is the ruby-bearing earthy clay of a brownish colour, which is mixed with a large percentage of exceedingly waterworn gravel composed of quartz and black tourmaline, amongst which is a quantity of mica.

In the red clay face of No. 26 mine, which is close to but at a higher elevation than the last-mentioned mine, there are quantities of small angular chips of quartz; whilst in the gem-bearing clay beneath are numerous flat crystals of graphite, similar to those so frequently seen in the crystalline limestone. In neither of these mines is any limestone to be seen, although the narrow belt of that rock which passes through No. 1 mine should cross near their position.

West of Pingu Hill, in No. 27 mine, which is a large cutting 25 yards long by

20 yards wide, and 10 feet deep, the brown loamy gem-bearing clay encloses large round blocks of decomposed pegmatite, which are reduced to the consistency and appearance of flour, with also some rusty black decomposed crystals. Some pits have been sunk in the floor of the mine to a depth of 18 feet, without reaching bed rock. The upper portion of one pit discloses layers of stream sand and pebbles, some 10 feet in thickness, mixed with brown loam. Beneath this is brown clay, in which are embedded large boulders of gneiss and pegmatite.

At No. 22 mine, near Sinkwa (Shinkwa) village, the section disclosed is some 150 feet wide, with a depth of 20 feet. The nature of the deposit shows a more bedded character than usual. The face of the mine on the west exposes 10 feet of brown clay, of which the upper portion is unproductive.

The clay in another part contains much water-worn pebbles, with blocks of gneiss and quartz which are not rounded. There is a band of blue clay lying horizontally in it, and at the base of the section are angular blocks of grey gneiss.

From a study of these sections it would appear that the brownish loamy clay, containing gems, has been made up of materials derived from the decomposition of gneissic rocks, mixed with a preponderating proportion of clayey matter and minerals derived from the disintegration of the crystalline limestone.

Amongst the ruby clays of this deposit are numerous pebbles of quartz and other rocks, which are completely waterworn, but the majority are not so, whilst in some instances scarcely any of them show any signs of attrition. For instance, the numerous bluish, opaque spinels are in their crystalline form of twin octahedrons, whilst perfect crystals of quartz are not uncommon, occurring with a small amount of water-worn pebbles of the same mineral. Also the rubies and red corundum, though sometimes found in a waterworn condition along with these, have usually, though broken, scarcely suffered from abrasion in any way. From these facts I conclude that none of the minerals in the ruby clays of this deposit have been transported to any great distance from the source of their origin, and that the rounding of some is rather to be attributed to attrition in pot holes, on rock surfaces, in the beds of small mountain streams. The fact of the minerals being intimately mixed with the brown clays, shows also that the whole deposit has been moved down the mountain sides without being submitted to forces sufficient to produce a thorough re-sorting of the component materials.

On washing the ruby-bearing materials of this deposit, and eliminating the clay and fine sand, the remaining portion is found to be made up of quartz, gneiss, pegmatite, black tourmaline, garnet, rock crystal, spinel, and ruby. In some Hmyaudwins, notably No. 1 and No. 2, a few sapphires have been found, but very sparingly. In some of these mines it is said that the upper red loamy clay contains rubies in infinitesimal quantity. In No. 2 mine large pieces of pale red, opaque corundum are found, some of which, though broken, retain a part of their crystalline form.

2. *Alluvium.*

In the larger valleys of the district there are extensive deposits of alluvial matter, consisting of clay, gravel, and sand, which have been laid down by the streams flowing through them. The materials of these vary in different portions of the same valley, being in the upper part of Mogok composed of a brown sandy loam resting upon coarse gravel, beneath which is an admixture of clayey materials containing gravel and sand, together with many rounded blocks of gneiss. In the lowest portion of the gravel and sand, rubies and quantities of garnets are found. This rests upon an under-clay which, in places, is a white floury kaolin containing white mica, the result of the decomposition of the bed rock. The thickness of the whole is from 10 to 12 feet.

Lower down the valley, in front of Mogok, the thickness of the top clay is from 15 to 22 feet, and the ruby-bearing sand and gravel beneath varies from 5 to 7 feet. Beneath this comes a stiff yellowish under-clay containing a few water-worn pebbles. The ruby-bearing material is composed of yellowish sand, in which are coarse pebbles, and rounded blocks of gneiss. It is difficult to say of what the remainder of the deposit is composed after the under-clay is reached, for the miners cannot be induced to dig deeper than the base of the ruby-bearing sand, the under-clay being soft and dangerous to sink through, its weight breaking their light timbering.

Near Taungwee the alluvium is composed of yellow and red loamy clay having a thickness of 24 feet, beneath which is from 3 to 4 feet of yellowish sand with large water-worn blocks of gneiss and pegmatite, resting upon an under-clay of a micaceous character, derived from the decomposition of pegmatite.

Between Taungnee and Mintada, away from the river, the alluvium is of a red and yellow loam amongst large blocks of pegmatite, at the base of which is a thin irregular layer of ruby-bearing gravel. The whole has a thickness of 15 feet, and rests upon the white decomposed bed-rock. Nearer Mintada the deposit is all of blackish clay and sand.

In the Yeboo valley, near the village of that name, it is formed of a brown loam passing into gray clay, of 12 feet in thickness, with dark grey ruby-bearing sand and gravel. I was unable to find any sections of the alluvium of the Kathay and Kyatpyen valleys, owing to there being no twinlones at work in that district; and the numerous remains of small round pits, long since abandoned, did not show the nature of the deposit passed through.

In the Injauk valley near Bernardmyo are old alluvial workings in the form of pits, some of which are 12 feet in depth, sunk through clay of bluish-grey and yellowish colours, with much slightly water-worn quartz gravel which came from the gem-bearing layer at the bottom. The greater portion of the excavated material has been washed away by rain. Some very perfect specimens of rock crystal are seen scattered over the surface of the ground. These mines, it is said, produced sapphires of good quality in former years.

After washing the sand for the rubies they contained, the gravel remaining is chiefly of fragments of quartz, gneiss and pegmatite, amongst which are spinel, garnet, tourmaline, and rock-crystal.

The following is a more detailed account of the deposit as examined in the pits at work. Between No. 8 and No. 9 mine, in a small section on the river bank, is a dark sandy loam resting upon a heavy brown clayey loam, with gravel and blocks of gneiss.

In Twinlone 6, near by, is 6 feet of dark brown loam on gravel in which is gneiss and pegmatite rubble, containing numerous garnets; and in the stream near by are huge rounded blocks of coarse pegmatite, some of which are 30 feet long and 15 feet high.

		ft.	in.
Twinlone 5.	Grey sand and gravel amongst large gneiss boulders	10	0
Twinlone 3.	1. Brown sandy loam	4	0
	2. Bluish-grey sand and gravel with garnetiferous gneiss rubble	3	6
	3. Ruby-bearing gravel and sand	2	6
		10	0
	The bedrock is a decomposed pegmatite.		
Twinlone 1.	1. Brown sandy loam	8	0
	2. Grey finely foliated gneiss and pegmatite rubble, embedded in sand and gravel	3	0
		11	0
Twinlone C.	1. Blackish mud and clay	15	0
	2. Dark greenish-grey ruby-bearing sand, with gneiss pebbles.	2	6
		17	6
Twinlone E.	1. Yellow loam at surface	2	0
	2. Dark loam	5	0
	3. Brownish clay, with gneiss rubble	13	0
	4. Yellowish ruby-bearing sand and gravel	6	0
	5. Stiff yellow under-clay—depth undetermined.		
		27	0+
1st Twinlone I had sunk near to Twinlone E.			
	1. Brownish-yellow clay	3	9
	2. Dark brown loam	2	3
	3. Drab-coloured clay	6	0
	4. Yellowish ruby sand and gravel, with gneiss rubble and a few large blocks of pegmatite	6	0
		18	0
	Yellow under-clay.		

In No. 4 bed was a sloping parting of grey clay, 2 feet thick at the lower end, and 6 inches at the upper.

		ft.	in.
2nd Twinlone I had sunk.			
	1. Yellow clay	18	0
	2. Yellowish ruby-bearing sand and gravel	12	0
		30	0

This pit did not reach the bottom of the ruby-bearing sand, but the miners refused to sink deeper.

		ft.	in.
Twinlone G.	1. Yellow clay and sand, with black sandy loam.	13	6
	2. Grey sand with gneiss pebbles forming the ruby-bearing portion	1	6
		15	0
Twinlone H.	1. Yellow and red clay and loam	22	0
	2. Yellowish ruby-bearing sand, with gneiss, pegmatite, and quartz gravel	3	6
		25	6
	3. Yellow micaceous under-clay.		
Twinlone K.	1. Red and yellow stiff clayey loam	13	0
	2. Yellow ruby-bearing sand, with large blocks of pegmatite and pebbles of gneiss	2	0
		15	0
	3. White floury micaceous under-clay.		
Twinlone M.	1. Brown and grey loam and clay.	12	0
	2. Ruby-bearing sand, with gneiss pebbles of variable thickness.		

The alluvial deposits at Nyoungouk, and along the northern side of the Mobay-choung from Nayo, are of two ages; one being the recent alluvium forming the flat valley of the river, and the other an old river gravel deposited at a higher level, which is seen at the base of the hills. This latter is composed almost entirely of quartz and quartzite gravel, which, in some places, is semi-consolidated by the percolation of water, charged with oxide of iron, derived from the red loam resting upon it. This covering is in part a hill wash derived from the mountain sides. The base of the old gravel is generally on a level with, or above the level of, the surface of the present river alluvium.

The latter is composed of a dark loam on grey clays and sands, as seen in the river banks.

In the extensive Hmyaudwin cuttings, on the north side of the river, fair sections of the old gravel are seen, where it has been worked for rubellite. One of these, at the foot of the hills, exposes the following section :—

	ft.	in.
1. Red homogeneous loam	50	0
2. Coarse quartz gravel and rubble in which are blocks of partially decomposed gneiss and water-worn bluish-black clay slate	10	0
	60	0

The section seen in a hmyaudwin face, close to Nyoungouk village, is as follows :—

	ft.	in.
1. Red loam	20	0
2. Yellowish sand and clay, with pebbles	10	0
3. White quartz gravel, mixed with a small amount of light grey and yellow sand, the whole being more or less iron stained. Amongst this are some blocks of pegmatite containing black crystals of tourmaline and small elongated water-worn blocks of hard dark-coloured clay slate in which are thin bands of quartz	10	0
	40	0

This gravel (No. 3) contains the rubellite and some garnet.

3. *Sandstone.*

About one quarter of a mile from Thebayetkin the crystalline limestone is covered, between that and the Irrawaddy river, by a deposit of grey, friable sandstone, probably of Tertiary age. The junction of these rocks is obscure. The sandstone beds are seen on the back of the Thebayetkin ridge, and in its face on the river bank, where a cliff exposes grey, friable sandstone, containing some small quartz pebbles, while water-worn blocks of a somewhat similar sandstone form layers in it. These beds dip south at an angle of 50°.

4. *Mica Schist.*

About one mile north of Lazee, a village situated on the north bank of the Mobaychoung, this rock is met with succeeding the gneissic rocks, which are there chiefly represented by pegmatites. The first exposure is of a light greenish colour containing a large percentage of silvery mica. This rock is again seen in the bed of the Mobaychoung, not far eastward of Lazee, inclining to the south-east at an angle of 38°. On the hills at Nayo loose blocks of mica schist are met with. From Nayo there is a fine view of the surrounding hill country, which is all deeply covered with red loam, presenting a sterile appearance.

It would appear that the pegmatite passes into mica schist, which probably forms a large tract of country to the southward.

Higher up the Mobaychoung, beyond Nyoungouk, there must be a further change in the nature of the rocks, probably from mica schist to clay slate, for waterworn pebbles of the latter are met with in the old gravel beds of the Mobaychoung, in the vicinity of Nyoungouk.

5. *Gneissic Rocks.*

As before stated, the rocks composing the earth's surface over the large extent of country embracing the ruby mines tract are composed chiefly of gneiss. These are covered in places by hill-wash on the mountain sides, and alluvial deposits in the valleys, but every here and there they appear at the surface in large exposures, enabling their varieties and structure to be studied. They contain bands of crystalline limestone of various thicknesses, which form a subordinate, though most important, part of the whole, insomuch that all along their outcrops are situated the gem mines which form the chief industry of the district.

The chief variety of gneissic rocks met with is a hard, coarse-grained, grey compact gneiss of somewhat massive character, which shows its true foliated structure by the weathering of its surface. This passes into a fine-grained gneiss of lighter colour and finer foliation, which in parts shows a slight contortion of its foliation. In a few places some of these show a very contorted foliation, and resemble the form once known in Germany as Stangel gneiss. Amidst the ordinary gneisses there occur massive and thin interfoliated layers of a rock composed almost entirely of quartz and felspar, the latter often in very large crystals, which sometimes assumes the character of an ordinary graphic granite. For this rock I employ the term pegmatite. It does not, as far as I was able to observe, constitute veins or intrusive masses, but forms a member of the gneissic series with which it is interfoliated, and possibly interbedded. This bedded character, both in this rock and in the gneiss, may be in appearance only, and due to tabular jointing, coinciding with the planes of foliation; but when examining such exposures as those of Chenitaung mountain and on Toungnee pass (to be afterwards described), one cannot but be struck with the resemblance of this to true bedding. The last variety to be mentioned, though not extensively developed, is seen on the range north of Kathay, near Ṣagiwa mountain, and also near Bernardmyo. It is of a coarse texture, of a greenish to greenish-yellow colour, and of a somewhat waxy appearance, containing in places sparsely scattered crystals of black mica, similar to that sometimes seen in the coarser pegmatites. A layer of dark hornblendic rock is met with in a few places, which may be a hornblende gneiss, but it occupies only a very subordinate position.

The main range on the south side of Mogok valley, from Chenitaung to Panma, is composed of gneiss of the massive, coarse variety; but to the southward it passes into the lighter and finer textured sorts, with interfoliated pegmatite, almost as far as the Mobaychoung.

The mountains north of Mogok, and onwards to Bernardmyo, are principally formed of the hard, finely-foliated variety; and a similar gneiss is also well developed south of Kyatpyen and Kathay.

The gneiss from the valley of Kyatpyen westward to Wapudoung is of the ordinary finely-foliated, grey variety, which near Shwaynambin shows a contorted foliation. There was no opportunity of examining the rocks more than superficially in passing over the road from Kabein to Thebayetkin, as the journey was performed on horseback in long stages, which left little time for stoppage on the way.

The strike of the foliation, and apparent bedding, varies from north-east and south-west on the south side of Mogok valley, to east and west on the southern slopes of Toungnee; then from south-west and north-east from Sagiwa to Pingu hill, and in a general east and west direction to Kabein, and, as far as could be made out, continuing in that direction to a point halfway between Nampan mountain and Kauklabin, where it curves round to the northward. Its dip is in a southerly direction at right angles to the strikes above enumerated, generally at angles of from 20° to 80°, while in a few places it is vertical, as seen in the Chenitaung range near Zelatnetaung. On the mountain side near Wapudoung it dips west at an angle of 45°, and evidently in the vicinity of that place it becomes horizontal, or nearly so, for beyond to within one quarter of a mile of Thebayetkin one of the great inclosed layers of crystalline limestone—the outcrop of which is seen in the gneiss on the mountain side above mentioned—assumes an almost horizontal position, forming the rock surface onwards. In two places only on this portion of the road are the gneissic rocks seen; one appearing about two miles west of Wapudoung, and the other some three miles from Thebayetkin. The first is where gneiss and pegmatite form a band for about half-a-mile; and the second where thin beds of gneiss crop out at very low angles in the crystalline limestone.

Crystals of garnet are more or less disseminated through the gneissic mass, and it is possible it contains rubies and spinels as well, but no evidence of this has yet been obtained.

On the path leading from Mogok to Ongain the foliation of some gneiss beds is slightly contorted, and dips at an angle of 80°.

Between No. 4 and No. 2 mines there is a large exposure of fine-grained, grey gneiss 40 feet in height, the foliation of which dips southwardly at an angle of 75°.

On the mountain side on the road from Mogok to Howet there is an exposure of solid grey gneiss 80 feet in height, of a fine-grained variety, containing garnets. Lower down the hill in the same mass are interfoliated layers of coarse, white, granular gneiss containing garnets of rounded and lenticular forms, very impure and oxidized in parts. Amongst them are flat, black crystals of a micaceous character. This section is an exceptional one as regards the inclination of the foliation, which inclines to the northward.

The dividing ridge between Mogok and Momeit valleys is very precipitous between the pathway in the pass and Chenitaung peak, where an extensive section is exposed of bands of gneiss dipping evenly to the south-east at an angle of 35°. So regular are these bands, that from a distance they greatly resemble beds of sandstone.

Here they are of finely foliated grey-and-whitish gneiss somewhat decomposed, in bands of from 10 to 20 feet in thickness. The last one, where further ascent was rendered difficult by the precipitous nature of the ridge, was a coarse white granular gneiss, containing little mica, but with large nodules of garnet. Near the top of the pass is crystalline limestone in the gneiss, occupying a width of 50 feet, and containing large crystals of white felspar and small crystals of graphite. Half-way down the mountain below this are some loose blocks of "Stangel Gneiss," outwardly bearing a resemblance to stems of fossil trees.

Towards the point at the head of Mogok valley, where the Yenee river emerges from the limestone, the red loam rests upon the semi-decomposed gneiss, with huge rounded blocks of the latter rock on the surface; the hills thus formed close in on both sides of the river, constituting a barrier, which separates the level bottom of the valley from a second extensive flat alluvial area, extending up to the head of the river.

Two-thirds of a mile southward of Mogok, in the narrow gorge of the Mogokchoung, is an exposure 300 yards in width, of dark-coloured, fine-textured gneiss in vertical bands, varying from a foot or two in width to 10 feet. Interfoliated with these are two layers of crystalline limestone, the first being 30 feet wide, in which is a band of gneiss one foot in width; and in the second, which is 20 feet wide, are several narrow vertical bands of dark-coloured, fine-textured gneiss. There are also bands of pegmatite in the gneiss, one of which is five feet in thickness. From this section, laid bare by the river, showing the limestone, when it is not visible along the range either east or west, owing to the covering of hill-wash, it must be inferred that in many other places there are small bands of crystalline limestone in the gneiss, which are not seen at the surface on the hill-sides. It is only the large bands of limestone of great thickness, whose outcrops stand out in jagged masses above the surrounding surface, that prove the existence of this rock and form an important feature in the geology of the district. In the limestone beds above mentioned, are violet-coloured crystals of garnet, and the same are also seen as accessories in the adjoining gneiss.

From Mogok valley, on the road to Momeit *viâ* Kyaukwa, up to the pass, where rock outcrops are visible, they are all of gneiss, thin-bedded and grey, with interfoliated coarse, whitish gneiss, and pegmatite containing garnets. At the pass itself all the rocks are whitish pegmatite. In a line with the dip of the gneiss on the peak close to Letnytaung (Lennu Taung), a flat-lying, grey gneiss is seen on this road, which probably is the same as that of 40 feet in thickness which caps the crystalline limestone of the peak, and does not coincide with the usual dip, but slants irregularly in a south-easterly direction at an angle of 35°. It may be that here there has been some disturbance, in the form of a more or less horizontal fault, or a "lateral thrust." To the east of the pass the mountains of gneiss are extremely decomposed to a great depth, and contain a band of pegmatite in which are bluish crystals of apatite Near by to the south, this rock contains large crystals o dark-coloured mica. From the pass down to the river in the bottom of the narrow valley and along to Kyaukwa, all the surface rocks immediately along the pathway are of finely-laminated gneiss, apparently inclining south.

South of the Yenee, near the village of Taungwa (Taungywa), not far from the bridge, on the hillside there is an enormous block of dark pegmatite, which contains a reddish felspar, and much quartz. This curious rock is rudely foliated, and resembles a block of gneiss, but differs in not containing any mica. Below this rock in the gneiss are three small veins of quartz, two horizontal, and one vertical. The only other places where veins of quartz were observed was on the road to Howet, where a small one occurs, at a short distance south of Kyatpyen; and near Kyauktaing village, where one of 18 inches thick could be traced for a short distance.

The first four miles along the new military road from Bernardmyo to Kathay, the cuttings disclose semi-decomposed gneiss containing coarse, light-coloured pegmatites, in some of which are small, round, decomposed crystals of a brown, iron-stained mineral, probably garnet. Near the dividing ridge on the same road, is a small section of decomposed gneiss which is foliated in various directions, and incloses rounded eyes of pegmatite around which its foliation curves.

The hill to the north-east of the cantonments of Bernardmyo is composed of evenly foliated grey gneiss, in parts of which are nests of white, finely crystalline quartz. In the stream at the foot of the descent from Taungnee to the Injauk valley are some blocks of a very dark-coloured coarse gneiss, hornblendic gneiss, and pegmatite. One quarter of a mile from the bridge across the Injaukchoung is a white quartz-schist, apparently interfoliated in the gneiss.

Near Thaungla the gneiss is seen in alternating bands of fine and coarse varieties, the former varying in width from a few inches to one foot, whilst the latter are of much greater thickness.

In ascending Sagiwa from the Kathay-Bernardmyo road, a set of massive, greenish-yellow beds of gneiss, containing in parts large scattered crystals of black mica, are crossed with ordinary gneiss near the top, on which is a coarse pegmatite. Resting on this is fine-textured gneiss with contorted foliation, enclosing white quartzite containing crystals of graphite. The peculiar greenish gneiss having a waxy appearance, is well-developed on the dividing ridge beyond Sagiwa to the north, and can be traced south-westward for over a mile towards Bolongui. This rock when weathered is on the surface of a light yellow colour.

From Kyatpyen for a mile south, the gneiss is thinly foliated and wavy in parts; and onwards to Nayaw (Nounghwai), some six miles to the south-south-west, it contains interfoliated pegmatite. At two miles from Kyatpyen the rocks are much decomposed, and landslips disclose the red, pink, and white colouring of the resulting clays and loams, similar to those seen on the south-east of Mogok valley. Close to the village of Nayaw is a section of coarse-jointed gneiss, dipping south-west at an angle of 50°.

Crossing the Yevoo, a quarter of a mile below Kathay, is a hard set of gneiss rocks showing a slightly contorted foliation, which forms a small fall.

In the gneiss from Kyatpyen valley head to Bolong there is an extensive exposure of pegmatite, of a coarsely crystalline texture, the greater portion of which is made up of large felspar crystals which have a satiny lustre. This rock differs from its other developments in having a large amount of whitish mica.

Not far from Pingu hill, on the west, there is a small section disclosing the junction of the gneiss and a limestone band. Here, at the plane of contact, the rock is of a nearly black colour, resembling a hornblendic gneiss ; and is in a band 4 feet in thickness, inclining south-west at an angle of 35°. This rock also occurs near Kyatpyen valley head, near Welloo, at No. 13 mine, and near Dattau ; and is evidently a continuous band adjoining one of the great limestone masses.

On the north side of Pingu hill, which is very steep and joined by a ridge from Kyauktaing, the rocks are of gneiss. Then for 50 feet of the ascent these, in large blocks, are mingled with masses of the limestone. They have evidently slipped down the uneven surfaces of the limestone beds, and in some instances have fallen into the open cavities in that rock. On the top of the hill the gneiss forms a thin layer, dipping south. From Panma, on the south, the winding path leading to the summit (5,660 feet) is on a comparatively easy slope over gneiss, until near the top, where there are thin limestone outcrops. The first portion of the ascent is of white pegmatite, succeeded by grey gneiss higher up. Near the top are some curious gneiss bands of 2 feet in thickness, which are very friable, somewhat resembling an altered sandstone. A block of limestone near the summit has a band of greenish rock in it, $1\frac{1}{2}$ inch in thickness, of a gneissose character.

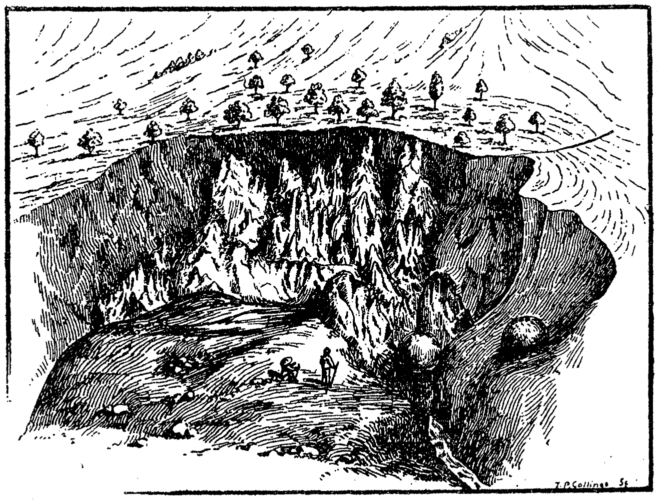
At the foot of Mandalay hill, not far from the late King's Palace, are bands of pegmatite of white, greenish, and reddish colours, in which is an interfoliated band of crystalline limestone, containing brownish mica crystals.

6. *Crystalline Limestone.*

I have deemed it advisable to give a description of this rock, and its mode of occurrence, separately from that of the gneiss in which it forms great bands, owing to its very interesting nature. As far as the limited investigations of the geology of the district went, it was only possible to partly trace out the extension of some of the larger bands, from the head of Mogok valley to Kabein ; and even the result of this work, to a great extent, must be looked upon as provisional only.

The outcrops of this rock are easily discerned crossing the mountain sides and spurs of the open portions of the country, in the form of dark grey masses rising above the surface of the enclosing gneiss. Their true white colour is completely disguised by a dark greyish *lichen*, which coats and clings tenaciously to their surface. On the other hand, on many parts of mountain slopes their continuity is completely hidden by the thick covering of hill-wash; while, in the valley bottoms, they are rendered invisible by the deposits of alluvial matters. But in many cases, in these positions, their existence is made known through the removal of these superficial deposits by the operations of the native miners, in extracting the clays containing rubies (see fig. 2).

Fig. 2.



Hmyaudwin No. 11.
Showing pinnacled surface of limestone where hill-wash has been removed.

It is of the usual composition and character of ordinary crystalline limestones, being made up of finely crystalline or granular limestone in layers, together with irregularly shaped bands of very coarsely crystalline limestone of white and bluish colours, which are interfoliated with the gneissose rocks. The surface of the limestone is always serrated and pinnacled by atmospheric action, and contains multitudes of sinuous caves leading down in the direction of the bedding planes to greater or lesser depths. One of those in mine *a* is said to have been followed by the miners to a depth of 390 feet. In some instances there are also horizontal caves traversed by small streams for considerable distances. At mine *a*, near Kyauksan, which is situated in a small depression on the limestone, the water led by a trench down the mountain to the mine, for the purpose of disintegrating and washing the ruby clay brought out of the tortuous natural pits, is led down an abandoned one in a somewhat turbid state, and finds its way to a cave, the mouth of which is at the head of the Kathay valley, some distance off. This cave, which I explored for a considerable distance, has a good-sized stream flowing in it, which, though rendered turbid by the mine's gutter, contains far more water than is artificially let into it. It has a winding course, sometimes along the planes of foliation but also frequently across them, and is from 20 to 30 feet in height in places.

There are eleven distinct limestone exposures between the falls on the Mogok-choung and the peak next below Toungnee on the southern slope of that mountain.

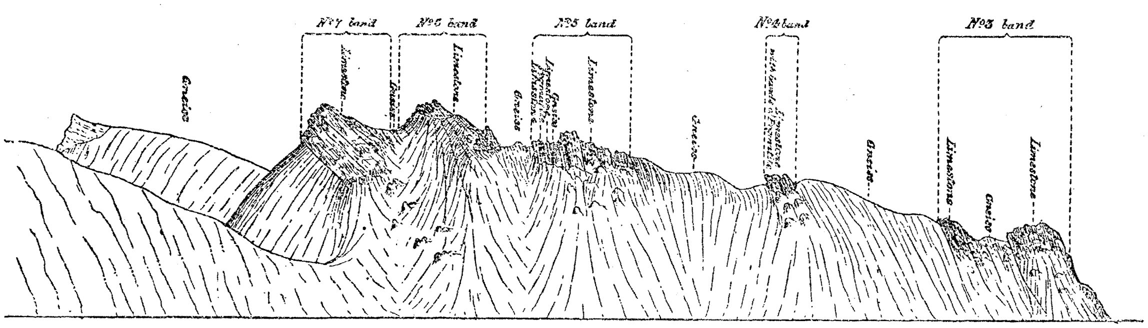
The long spur from this peak down to Mogok valley discloses the existence of nine of these; one more is seen in the valley, and one in the above-mentioned falls. These vary in width, across their outcrops, from 20 feet to 700 feet.

The principal band No. 3 (see fig. 3), along which the most important mines are situated, is some 300 feet in width and, as far as it can be traced out, extends in a sinuous line from Dattau through the end of Letnytaung spur, on the edge of Mogok valley, onwards in a westerly direction through Bobadaung. There it curves in a south-westerly direction past Pyanbin to Pingu hill, where its course is altered to the north-westward as far as Bolong. From thence it passes through Welloo and Kyaukmyo to Kabein.

Beyond this westwards there was no attempt made to fully investigate the limestone band further; in fact, had time allowed, the work would have been almost rendered impossible, owing to the trackless nature of the great forest-covered mountains of this portion of the district. In places, however, where some of the bands crossed the roadway onwards, they were noted; and I found that (as before-mentioned) one band, after curving to the northward in the neighbourhood of Wapudoung, became almost horizontal, forming, with but one exception, the surface rock along the road nearly to Thebayetkin (see map, fig. 11).

Although these bands are somewhat parallel to each other in parts, they are not so in others, and it would be impossible to expect much regularity in their relations to each other, or much conformity in the width of each for any distance, associated as they are with a class of rock which must have been subjected to considerable disturbance and displacement. In all cases their dips are conformable to the foliation of the gneissose rocks (see fig. 3).

Fig. 3.



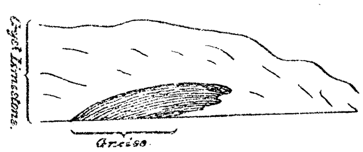
Sketch of part of Letnytaung spur, showing the limestone bands in the gneiss.

Commencing with the small bands at Mogokchoung Falls, and ending with that on the peak next below Taungnee—a distance of four miles—as far as I was able to roughly estimate them, their widths were as follows:—

No. 1. 50 feet; 20, and 30 feet, in two bands, in Mogokchoung Falls.
,, 2. 150 ,, on the north side of Mogok valley.
,, 3. 300 ,, in two bands of 200 and 100 feet, with 100 feet of gneiss between, on the north edge of Mogok valley, at end of Letnytaung spur.
,, 4. 50 ,, on Letnytaung spur.
,, 5. 400 ,, in two bands of 300 and 100 feet, with 100 feet of gneiss between, on Letnytaung spur.
,, 6. 250 ,, close to Letnytaung peak.
,, 7. 400 ,, at Letnytaung peak.
,, 8. 50 ,, between Letnytaung peak and that below Taungnee.
,, 9. 300 ,, ,, ,, ,, ,,
,, 10. 700 ,, ,, ,, ,, ,,
,, 11. 70 ,, in peak next below Taungnee.

The bands from No. 2 to No. 11, inclusive, occupy a distance of $2\frac{1}{2}$ miles, and their collective thickness, across their outcrops on the surface, is about 2670 feet.

Fig. 4.



Gneiss in crystalline limestone.

Small bands of gneiss are frequently seen in the crystalline limestone (see fig. 4), as well as those of pegmatite in a few instances. As a general rule the former are evenly foliated, and apparently undisturbed, as far as the small sections exposed allow them to be seen, but in one or two instances this is otherwise. For instance, a small band, 2 feet 6 inches wide, in the limestone (No. 7), on the side of Letnytaung spur, is contorted and twisted in a remarkable manner, both the gneiss and limestone having the appearance of being at one time subjected to a vertical, and also lateral pressure, by which they were rendered, as it were, of a plastic state (see fig. 5). Near by, on the mountain top, a band of gneiss, 1 foot 6 inches wide, seems to have been ruptured by the limestone being forced through it, when the whole appears as if it were subjected to an intense pressure when in a plastic condition (see fig. 6).

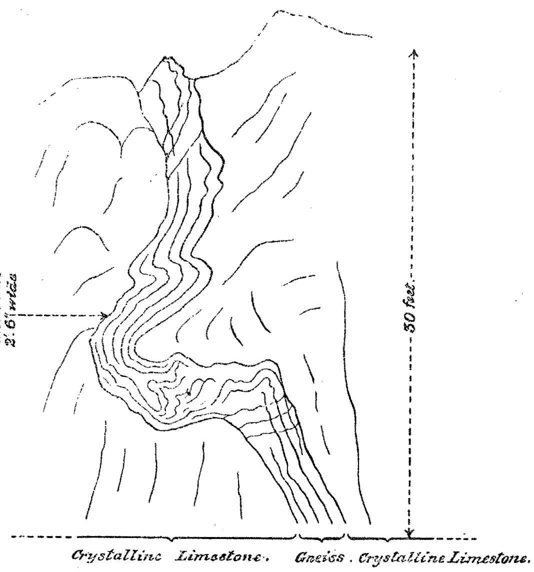
A small section of these bands is seen on Taungnee Pass, where they are undisturbed, their planes of foliation dipping south at an angle of 55°.

This is as follows (see fig. 7):—

1. White crystalline limestone, containing spinel.

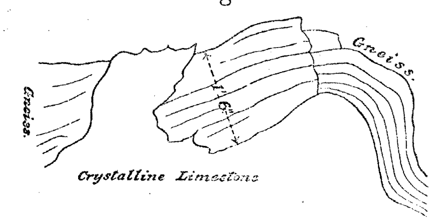
2. Finely foliated grey gneiss, slightly decomposed, 4 feet in width.
3. White crystalline limestone, 2 feet.
4. Thinly foliated gneiss, 6 feet.
5. Coarsely crystalline white limestone, containing violet-coloured spinel and green crystals of augite, together with graphite, 16 feet.
6. Finely foliated gneiss, 15 feet.
7. Coarsely crystalline limestone.

Fig. 5.



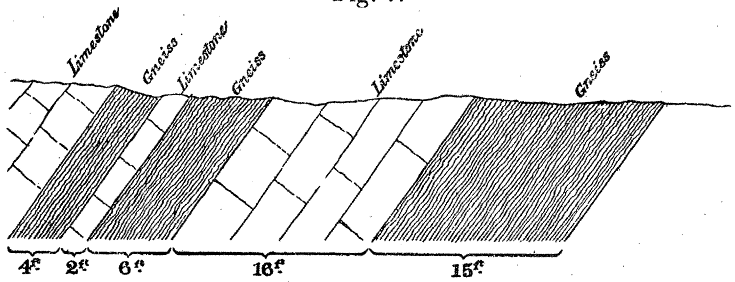
Highly contorted gneiss and crystalline limestone.

Fig. 6.



Crystalline limestone forced through gneiss.

Fig. 7.



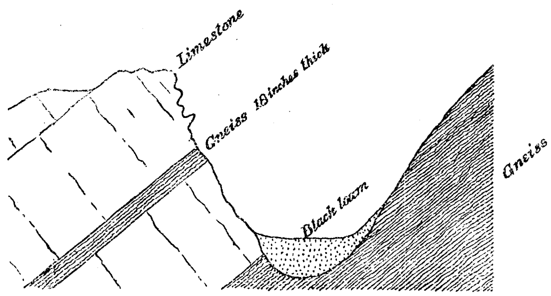
Section on Taungnee Pass.

Another section, occurring near mine No. 15, is as follows (see fig. 8):—

1. Coarsely crystalline white limestone, containing brownish mica crystals, in parallel planes giving it a schistose structure, which are most numerous at the plane of contact with the next band.
2. Hard grey compactly crystalline grey gneiss, 18 inches.
3. Coarsely crystalline limestone, 8 feet.
4. Finely foliated grey gneiss.

These dip to the south-south-east at an angle of 40°.

Fig. 8.



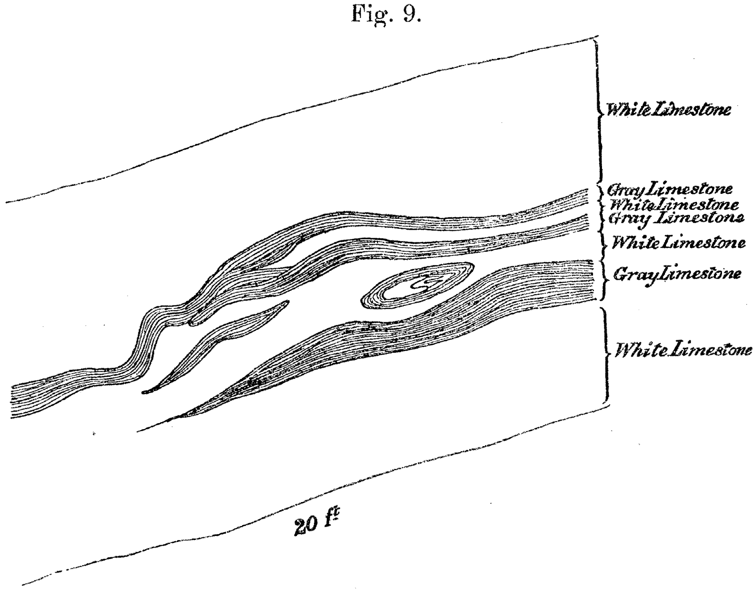
Section near No. 15 Loodwin.

It is difficult to find good sections showing the junction of the large limestone bands with the main masses of gneiss, where they could be easily observed. In those few places where an examination was rendered comparatively easy, it was seen that near the plane of contact the limestone has a schistose appearance, owing to the contained crystals of whitish and brownish mica being arranged in planes parallel to the foliation of gneiss. In that part also appeared to be a greater variety of accessory minerals, such as graphite, white opaque felspar, and violet-coloured spinel. Further away the limestone became more coarsely crystalline, passing into a sort of white opaque, or bluish and greyish semi-transparent calc-spar, in rhombohedrons which sometimes attain a size of over six inches across.

The best section of the junction, as well as of one of the main limestone bands, is seen near Pyagone, where the latter (probably No. 3 band) crosses through a ridge from Bobedaung. Even here it is difficult to accurately examine this, owing to the somewhat broken surface of the outcrop, and to the covering of hill-wash upon it in places. The junction is very clearly defined in a small cliff-like section at No. 16 mine. Here the grey gneiss, of an evenly and finely laminated variety, rests on the limestone, its foliation dipping to the south, like that of the latter rock, at an angle of 45°. Although the plane of contact is clearly defined, yet the gneiss firmly adheres to the limestone. Tracing the section northward it is as follows:—

1. Finely laminated gray gneiss.
2. Crystalline limestone, containing spinel, gneiss, felspar, &c., 18 inches.
3. Finely laminated gneiss, 6 inches.
4. Coarsely crystalline limestone, containing graphite, light-coloured mica, and green crystals of augite, 50 feet.
5. Very coarsely crystalline limestone in irregular shaped bands, alternating with ordinary crystalline limestone, probably 150 feet.
6. Finely crystalline limestone, containing graphite, mica, and spinel, probably 100 feet. At mine *e*, in this, there is a band of grey gneiss, the foliation of which is inclined at an angle of 75°, corresponding with the inclination of the limestone in this part.
7. Gneiss underlying the limestone just beyond mine *e*, probably 600 feet.
8. Band of crystalline limestone, probably 150 feet.
9. Gneiss.

Fig. 9.



Section showing bands of grey limestone in white limestone at mine *d*.

This band is again seen cropping out in spurs near Pyanbin on both the east and west sides of the basin-shaped depression at *b* mine. On the eastern side it has been exposed by the detrital covering, having been removed from its jagged surface, and slopes south-easterly at an angle of 75°. On the western side it has the same dip, and rests upon the gneiss at the same angle. It again appears on the eastern side of Kathay valley, but its greater portion onwards is hidden by alluvium as far as Panma village. From thence onwards it passes through the north-eastern side of Pingu hill, and is seen outcropping here and there through Bolong, Welloo, and Kyaukmyo, to Kabein (see Map, fig. 11, p. 183).

Some of the large bands north of Letnytaung pass eastwardly into the Kyaukwa valley towards Momeit, and eastwardly up the slopes of the Taungnee range, and over it into its descent northwards, where they are crossed on the road from Kathay to Bernardmyo.

Besides the band above mentioned, another one is seen on the western side of Kathay valley, which is probably the western extension of that at No. 1 mine. Where the new road crosses it the cuttings disclose 60 feet of crystalline limestone, then 30 feet of gneiss, and then 120 feet of limestone. To the east of this section there is a deep depression, in which this band is seen, but beyond, all the way to Mogok, its outcrop is not again visible at the surface. It is hidden by the alluvium of Kathay valley, but at mine A, at Kyatpyen valley-head, at Ya-a, and at Kyaukpyasa, it is seen again. At the latter place one portion of it constitutes a peak composed of coarsely crystalline limestone 40 feet in width, rising 50 feet above the gneiss on its north side, and forming a precipice on the south side of between 300 and 400 feet in height. A large solitary crystal of light-coloured mica of 4 inches across is seen in one part of it.

This variety of rock is met with in other places, viz. : on the mountain slope on each side of Taungnee pass and elsewhere, rising from the surface of the limestone in narrow, uneven developments, which greatly resemble the ruined walls of an old fortress, some being 15 feet in thickness, and as much as 30 to 40 feet in height.

Halfway between Mogok and Kathay are the outcrops of two small bands of limestone, which are probably an extension westward of the two seen in the Mogok-choung falls.

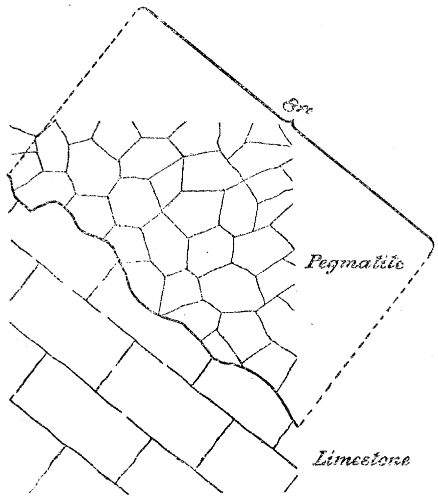
In the limestone bands No. 4 and No. 5, on Letnytaung spur, there are bands of coarse pegmatite containing large black mica and tourmaline crystals. One of these in No. 5 is 15 feet in thickness, and it is difficult to determine whether it is intrusive or not. It appears to be more vertical than the enclosing rock.

On the pass at the head of Kyatpyen valley there is a section showing a junction of whitish porphyritic pegmatite (in which are large crystals of felspar) and coarsely crystalline limestone. The former rests upon the latter, adhering firmly to it, and seems to fill the inequalities in the limestone surface. These dip south at an angle of 40° (see fig. 10). In places we find an interfoliation of white and grey limestones (see fig. 9).

From Kabein, the new government road runs in west-north-west direction past Kinua to Shwaynambin, leaving the main limestone outcrops to the south; but not far on from Kinua a high peak of gneiss on the right is seen, capped by a band of limestone dipping north-west at an angle of 20°. It would appear that a great boss of granite, which I had no opportunity of examining, has forced up the gneiss and altered the dips from southwardly to northwardly. Before arriving at Shwaynambin a band of limestone is seen in the gneiss, and another small one a little past that village. From this the general direction of the road to Nampan mountain is south-west, so that it again crosses limestone bands, which are undoubtedly some of those extending westwards from the ruby mines. The first of these, which is crossed between

Nampan and Kyauklabin, at about two miles from the latter place, appears to be only 90 feet in width. Another similar outcrop is seen before coming to Kyauklabin, and the next is crossed beyond that place, dipping south at an angle of 45°. These are followed by a few very small bands.

Fig. 10.



Section on pass between Kyatpyen and Kabein.

Descending the mountain to Wapudoung, the tortuous-graded road crosses and recrosses a thick limestone band all down the hill, interbanded with gneiss. Where this is first met with on the mountain top it appears to dip southwardly at an angle of 45°, while half way down it seems to incline to the west at a much lower angle. It would appear that this band of limestone, and the gneiss as well, curves sharply round from west to north, and becomes almost horizontal in the vicinity of Wapudoung, further on continuing with slight undulating dips* in that position all over the country to the vicinity of Thebayetkin. On approaching the latter place, its surface is covered in places with white marl, derived from its disintegration; while the beds of streams are coated with calcareous tuff. Beyond this, for a quarter of a mile to the Irrawaddy river, the rocks are of sandstone.

In the Sagyin district, 24 miles northward of Mandalay, the crystalline limestone forms a line of hills, surrounded by the alluvium of the Irrawaddy river, trending north and south. Of these, two are ridge-like, while the third, about one mile to the north of them, is formed of a low group. The most southern hill, rising to a height of 500 feet, is one mile in length, and has a width of a quarter of a mile at its base. This, and the next, slope gently towards the east with the dip of the limestone, but very steeply to the west, owing to the jointing of the limestone being at right angles to the bedding.

* The general inclination is at an angle of about 1° to the west.

On the southern hill about its centre, and halfway up its eastern slope, are some large quarries, where a granular limestone has been obtained, from which most of the multitude of images of Budda, with which the pagodas of the surrounding country are supplied, have been sculptured.* From these quarries a mass of limestone was excavated, from which was sculptured a huge Godda (Gautama) for the Arakan pagoda in Mandalay. The mass was so bulky that a canal was constructed from the foot of the hill to a side channel of the Irrawaddy, in order to convey it to Mandalay. The largest quarry of the six to be seen there, is 100 feet long, 50 feet wide, and 30 feet deep. The limestone bed quarried is from six to eight feet in thickness, of a pure white to pale bluish-grey tints, and apparently free from foreign ingredients. Its dip varies from an angle of 27° to 40°.

Filling the interstices and clefts in the limestone of the southern hill, is a semi-consolidated red earth, somewhat resembling laterite, which has been derived from the disintegration of the limestone and gneissic rocks, and which is said to sparingly contain light-coloured rubies. This material in the second hill is of a more consolidated nature, and of a greyish-red to reddish colour, forming irregular layers of from 2 inches to 18 inches in width. Near the southern end these have been extensively excavated over a tract 200 yards in length on the slope from the base up, and of 100 yards in width, in order to obtain the embedded rubies. With these are associated crystals of spinel and water-worn pebbles of brown hydrated oxide of iron, the latter showing that they, and the accompanying minerals, have been deposited along with the red earth in their present position. Some of the clefts have been filled with a dark-coloured earth. A few small pieces of gneiss are seen in the red earth, which may have been derived from thin bands of that rock in the limestone.

The enclosing bluish-tinted, coarsely crystalline limestone beds are as seen immediately underlying the granular rock of the quarries in the southern hill.

A specimen of limestone, which I obtained at the old workings, contained pale pink crystals of ruby, with iron pyrites, and purplish to blue crystals of sapphire.

The rock forming the third hill, on its eastern side, is a coarsely crystalline bluish and white limestone, one layer of which contains rubies. Here the rock has been blasted along a line, some 5 feet wide, up the slope of the hill, for the purpose of obtaining them.

On the north-west side of this group is an old cave working, together with a pit in the alluvium close by, which were formerly called the Royal Loo of King Mindoon.

In the main set of limestone bands passing through Letnytaung spur, not far from the Momeit road, and one mile north-east of Mogok, is situated the quarry which was formerly worked for the extraction of rubies from the matrix. The short limestone outcrop there exposed, traced from its southern end northwards, shows some 40 feet

* This rock takes a fine polish, and in Mandalay is known by the name of Alabaster, from being mistaken for that substance.

of white crystalline limestone, then a wide bed of white granular limestone, which abuts against a crystalline limestone of a few feet in width, in which are bands of reddish-brown mica crystals, graphite, small crystals of felspar, reddish spinels, and light green augite. This passes into a coarsely crystalline semi-opaque limestone (the matrix of the ruby) of about 20 feet in width; beyond which comes white crystalline limestone extending for some 90 feet, to where it is seen in some caves, of a coarsely crystalline variety.

Although the bedding of these is somewhat obscure, yet they evidently dip slightly to the southward.

The quarry, which is in the coarsely crystalline semi-opaque limestone above mentioned, is 20 feet wide at the face, and has been cut in for 15 feet, to where a small drift in its bottom has been advanced a short distance, making the entire length of the cutting at that part some 30 feet.

The rubies are found in the rock over a space of 6 feet in width, extending almost vertically from the bottom of the quarry to the surface of the ground; while the direction of the productive portion slopes to the south at an angle of 70°. On either side of this the rock changes from a bluish-grey to pure white. Along the centre line, where the rubies are most numerous, are small developments of a greyish mineral (diaspore), enclosing small crystals of iron pyrites, and where these occur the miners assert that the rock is the most productive. There is also a small irregular vein-like structure of the same mineral traversing this part for a short distance. Besides these there are small dull-greenish crystals of disaspore, and light green crystals of augite. In some of the specimens I obtained by blasting, magnetic pyrites was found in contact with the rubies.

At the mines close to Bobedaung village there are some fine beds of statuary marble, similar to those seen at the ruby quarry at Mogok; and here the adjoining coarsely crystalline limestone has been quarried for the rubies it contains.

This band is evidently the western extension of the one in which the Mogok quarry is situated. A cave working near by, called the Royal Loo, was formerly considered to be a very rich one. Moung Guy, a Mogok mine owner, informed me that when this mine was opened many years ago, the bones of a large animal were discovered in the ruby clay and loam in the cave's entrance, amongst which a number of fine rubies were found. He had seen one of these bones some ten years ago, and from his description it was evidently a rib of four inches in width.

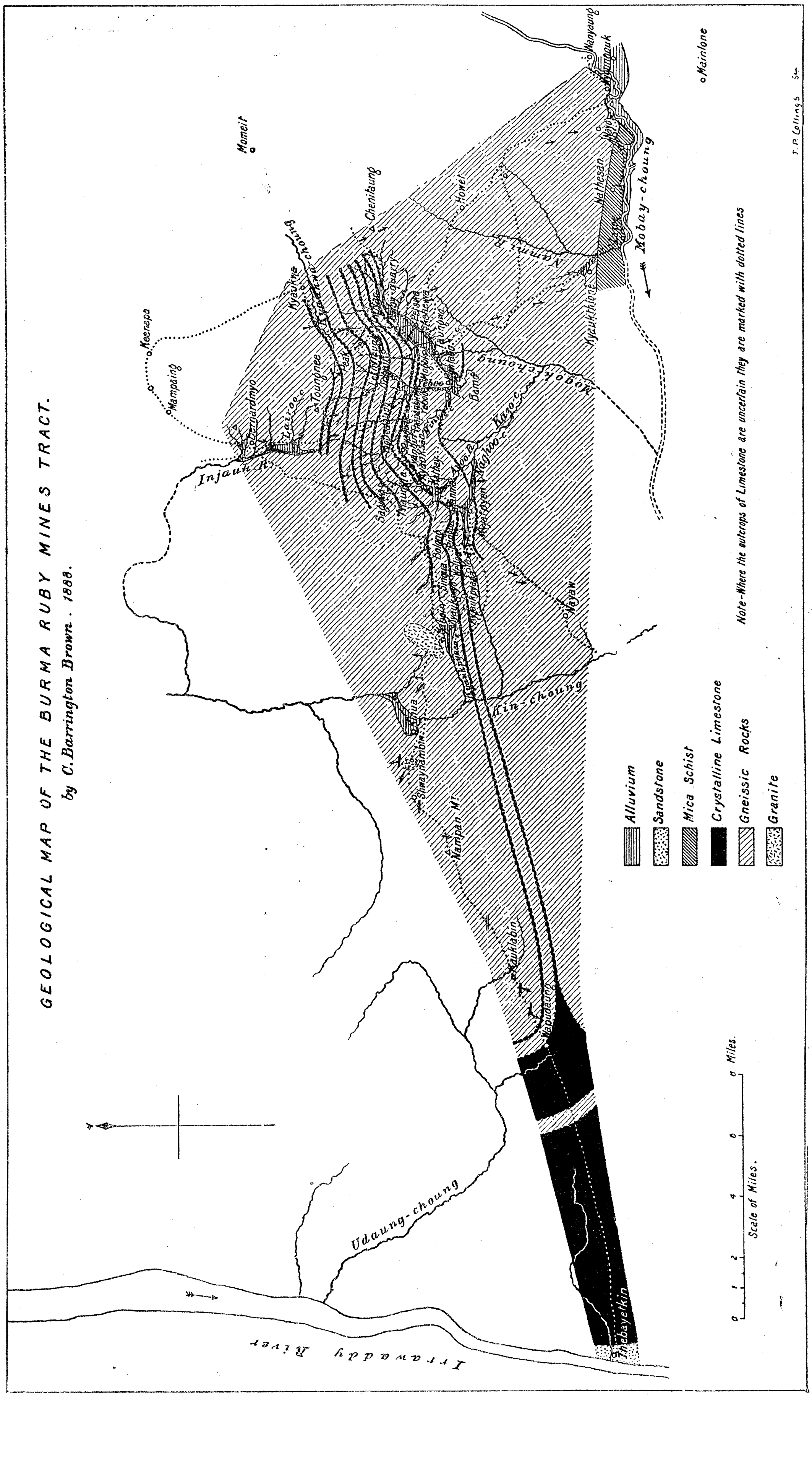
Between Thaungla and Pyanbin, in the continuation westward of the same band, rubies have been found in the limestone matrix.

7. *Granite.*

There is a large exposure of grey granite near Kabein, which there was no opportunity of examining, except a very small portion of it crossed on the new road. This is probably a pegmatite.

C. B. B.

Fig. 11.


GEOLOGICAL MAP OF THE BURMA RUBY MINES TRACT.
by C. Barrington Brown. 1888.
Alluvium
Sandstone
Mica Schist
Crystalline Limestone
Gneissic Rocks
Granite
Note–Where the outcrops of Limestone are uncertain they are marked with dotted lines
Scale of Miles.
Miles.
Irrawaddy River
Udaung-choung
Kin-choung
Mobay-choung
Injaun R.
Momeit
Mainlone
Keenepa
Mampaing
Chenikaung
Thebayelkin

V. Economics. (See Map, fig. 11, p. 183.)

1. *Mines.*

Mining for rubies is carried on in three ways, according to the different positions of the ruby-bearing deposits.

In the case of the alluvial deposits, where the sands and gravels are in a layer below the level of the beds of the rivers, they are reached by sinking pits called by the miners Twinlones, which, in the Shan language, means Round pits. Formerly these were made round and of small diameters, but now they are sunk square and of large size.

Where the ruby-bearing material is in hill-wash it is reached by open cuttings called Hmyaudwins, which means Water-mines.

And where the ruby earth is dug out of natural vertical tunnels and caves in the limestone, the excavations are known by the name of Loodwins—that is, Crooked or Twisted mines. To these may be added a fourth class of mine where the rubies occur in the coarse crystalline limestone (their matrix), from which they are obtained by blasting the rock; and these may be termed Quarry mines.

(*a.*) *Twinlones.*—These pits vary in size from 2 to 9 feet square. The mode of sinking and timbering these is as follows:—After a few feet have been excavated, strong posts, 12 feet in length, are driven down in each corner, and in the case of one 9 feet square, three more posts are driven at equal distances apart along each side. Short timbers are wedged across between each, and at intervals of about two feet light flat timbers are placed across each way. Wattles and dry grass, or twigs with leaves, are forced in the spaces between the upright posts to support the clay walls. This method of timbering is continued with the sinking to the bottom of the pit. When the excavation reaches the ends of the uprights, another set of posts is driven down inside the first, and these generally pass through the ruby-bearing sands and gravels. If necessary a third set is put in. Upon completing the pit and having sent all the ruby sand to the surface, the timbering is taken out for use in a new pit. Round pits at the present day are few in number, and are sunk merely to test the presence of the ruby sand, but, as seen in old workings in the Kyatpyen valley, and elsewhere, they must have been formerly extensively used instead of those of square shape now in vogue. The balance poles used both for hoisting the materials excavated, and the water accumulated in the pits, are made of strong bamboos. A large basket, filled with stones, is used as a balance weight at the butt, and to the long end overhanging the pit is attached a rope, or thin pole, carrying a basket. Some pits have five of these balance poles. Water-tight bamboo baskets are used for hoisting out the water. Some shallow twinlones are kept free from water by rude but ingenious bamboo pumps, placed in a slanting position.

The ruby-bearing sand is placed in heaps, and washed in small flat baskets made of the outer portion of the bamboo, somewhat similar in shape to the wooden batea. Their mesh is such that small particles of mineral matter will not pass through, while the water is all drained off. As soon as one pit is finished, generally within eight to ten days for a large one, and four to five for a small one; another pit is commenced near by.

(*b*.) *Hmyaudwins.*—These, the most numerous of all the classes of mines, are open cuttings of an elongated form, the lower ends of which are open to a hill or gully side. On commencing this sort of mine some outlay of capital is required, in order to bring a supply of water from some adjacent or distant stream, along the mountain sides to the head of the working. In one instance one of these gutters is over two miles in length. Where a ravine intervenes, the water is conducted across in a number of bamboo troughs laid side by side, supported on a bamboo structure, held together by strong cross pieces and stays. The water is delivered at the head of the cutting through bamboo poles, the ends of which are closed, the water passing through an opening in their top which causes it to fall in a more or less scattered manner. It flows away through a trench in the bottom of the working, which forms a ground sluice.

The operation of excavating the ruby-bearing portion is performed with long and short-handled spuds, and the stuff is thrown in heaps, upon which the falling water is directed. As the face of the cutting becomes undermined, the superincumbent clay and loam slips down and is washed away. The large stones in it are thrown to one side in heaps, or formed into walls to support the refuse, as well as the sides of the ground sluice, which is advanced towards the face of the working as the process of excavation proceeds.

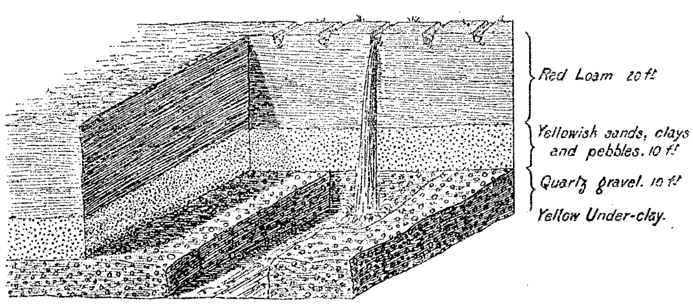
When the ruby-bearing material has been sufficiently softened by the falling water, the larger stones are picked out and thrown to one side, the remainder being hauled with hoes into the upper end of the sluice, where it is puddled. Two or three wooden riffles, of two feet or more in height, arrest the sand and gravel containing all the minerals. This is taken out, placed in basket bateas and washed clear of the remaining clayey particles when it is carefully searched for rubies, spinels, &c. The ruby sand which may escape from the upper portion of sluice is collected behind riffles placed along its entire length, and washed from time to time; but the principal and valuable portions are procured from the first 12 feet of the sluice head.

The extensive Rubellite Mines at Nyoungouk (see fig. 12) are worked somewhat on the Hmyaudwin principle, the water being delivered by a number of short bamboo spouts placed along the top of the face of the cutting, for the purpose of removing the top clay and for softening the binding material of the gravel, which contains the stones sought for. The work of excavation is very neatly executed, the sides as well as the face being made vertical. By dashing water against the exposed face of the layer of gravel and sand, with shovel-shaped baskets, the miners are enabled to see the rubellites and pick them out by hand. All the produce of these mines is sent to

China, where pink rubellite meets with a ready sale, but there are few purchasers of it in the European market. The transparent pink variety having an internal feathery structure, is most highly prized.

(*c*.) *Loodwins*.—Although at the time of my investigations only eight of these mines were in operation, the immense number of old cave mines to be seen in the crystalline limestone attested to the importance of these in former times. From there, it is said, have been procured the finest and largest rubies discovered in the whole district. Without doubt the rubies in them have been liberated from the rock itself, by the action of water and deposited amongst detrital matters in the sinuous channels, caves, and interstices in it, which extend in every direction and to great depths. The brownish clayey loam which fills these interstices and contains the rubies, is derived chiefly from the disintegration of the limestone.

Fig. 12.



Rubellite Mine at Nyoungouk.

Provided with small short-handled spuds, baskets, and small oil-lamps, the miners descend the pits, dig out the loam, which in instances where these are very tortuous they bring to the surface themselves; but usually the proceeds of their work are hoisted up perpendicular pits sunk in wide fissures by means of balance poles. By these pits, and tunnels connected with the workings which form passages from one to the other, ventilation is procured.

Blasting with gunpowder manufactured by the natives has sometimes to be resorted to.

In these mines no ladders are used, the miners descending and ascending the narrow tortuous passages with apparent ease.

Owing to the fissured nature of the limestone, there is usually no water to contend with in the workings, and none is used for softening the loamy clay, which is taken directly to the nearest water-supply and there washed in baskets as in the cases before described.

The depths of some of these earth-filled natural shafts is very considerable.

(*d*.) *Quarry Mines*.—These were formerly worked in four places, viz :—

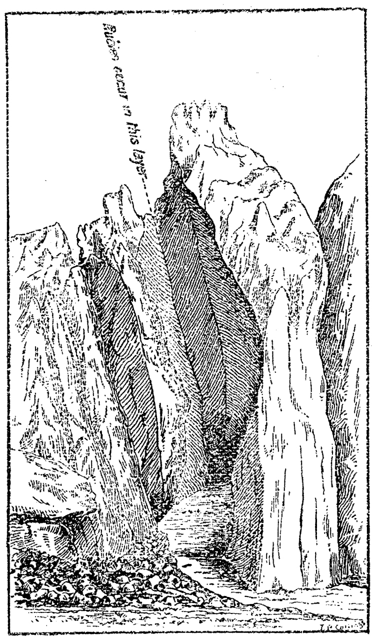
1. At the Ruby Quarry near Mogok.

2. At Bobedaung in the Royal Loo.
3. At Taungla.
4. At the northern hill of Sagyin.

Previous to my examination of the mines no true rubies had ever been seen by Europeans in their matrix, though crystals of opaque reddish corundum had been discovered in limestone in other parts of the world. It therefore became an interesting matter to discover whether the ruby existed in this celebrated ruby-bearing tract in the matrix.

Failing to discover anything but red garnets in the gneissose rocks, and red spinels in the crystalline limestone, I endeavoured, by questioning the mine-owners through

Fig. 13.



Ruby Quarry and Cave.

my interpreter, as to whether they had met with the ruby enclosed in rock, but at first without success. They must have known that it had been found, but were evidently loth to acknowledge it, or offer any information on the subject. My interpreter, upon whom the importance of making the fullest inquiries was constantly impressed, at last learned from a miner the locality of the Ruby Quarry in limestone at Mogok, from which he had extracted rubies by blasting.

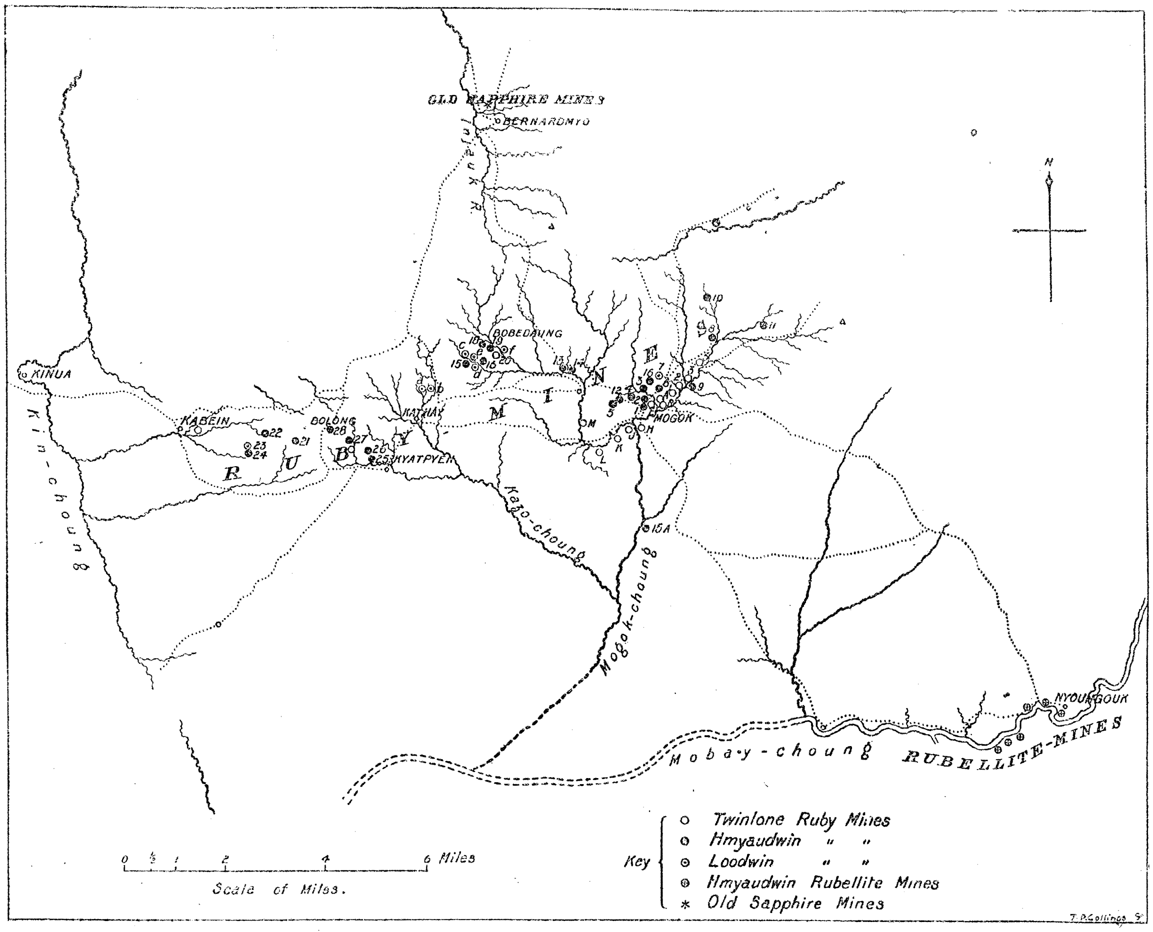
Upon examining this, no rubies could be seen in the face of the rock, but on getting two men who had worked there previously to put in a few shots and blow down a block, I had the gratification of seeing rubies of fine colour in the pure white limestone for the first time.

This quarry had been worked for fifteen years up to the time of the British occupation, when the authorities prohibited the use of gunpowder by the miners; but the fact was unknown to the officials or anyone visiting the mines previously to the date of my obtaining the specimens.

After this, one of the leading mine owners communicated to me the localities where the matrix had been worked for rubies.

The men whom I employed in a period of ten days procured fourteen good-sized rubies, besides numerous smaller ones, from $1\frac{1}{2}$ cubic foot of rock. After drilling

Fig. 14.



Map showing the position of the gem-mines of Upper Burma.

shallow holes and blowing down small blocks of limestone, they proceeded to break them up with hammers, and so obtained the specimens; but, owing to the jarring of the rock by powder and hammer, the rubies disclosed were all more or less injured, so that their commercial value was greatly reduced. These miners formerly obtained in this way rubies to the value of Rs. 200 per month, and on one occasion extracted a ruby which they sold for Rs. 300. No doubt there are other places besides those mentioned where rubies exist in the limestone, and when a process is found by which the rock may be cut out and burned in a kiln the contained precious stones will be procured uninjured, and in sufficient numbers to make this mode of obtaining them a source of profit.

I had some blasting done at Sagyin, which disclosed a few small off-coloured rubies, of no value, in the rock. The rubies obtained in the second hill in the consolidated red earth have hitherto been looked upon as being in the matrix, but this is not the case.

The foregoing description of the manner in which these mines are worked by the natives tends to show how primitive were the modes adopted at the time of my visit in 1888. In the hands of Europeans, with capital at command, the quantity of precious stones produced should be greatly increased were proper methods of working adopted. The great drawback to Twinlone mining is the quantity of water in the ruby-bearing gravel, and it would be a costly matter to drain such valleys as Mogok, Kathay, Kyatpyen, and Yeboo. But, could this be effected in the Mogok Valley there is a large quantity of ruby sand and gravel still remaining to be dealt with.

In some places adits could be driven at the foot of the hills into the limestone, thereby tapping the deposits in its caves and natural channels, which, from experience gained by native miners, is known to be more or less rich in rubies.

In February, 1888, the number of mines, consisting of Twinlones, Hmyaudwins, and Loodwins, was 77, employing 771 native miners. No quarry mines were then in operation, owing to the prohibition placed on the use of gunpowder by the Government. For the same reason, many of the Loodwins were lying idle. C. B. B.

VI. Petrology.

The large and interesting collections brought home by Mr. C. Barrington Brown, which have been submitted to me for study by the Secretary of State for India, consist of the following classes of materials :—

(*a*) Specimens of the rocks of the district—gneisses, granulites, pegmatites, crystalline limestones, &c.—collected *in situ*.

(*b*) Selections of rock-fragments and minerals found in the ruby-bearing gravels. The rock-fragments are for the most part similar to those collected *in situ*; but they are often water-worn and are sometimes in a very disintegrated condition, owing to the action of atmospheric denudation.

(*c*) Specimens of the reddish-brown earth in which the rubies and other gem-minerals occur.

(*d*) Samples of the materials obtained by the rough washing of the ruby-earths before picking.

In dealing with these materials I have studied the rock-specimens, whether collected *in situ* or as derived fragments in the gravel, by the aid of thin sections under the microscope, where necessary isolating and submitting to different physical and chemical tests their several constituent minerals.

Specimens of the ruby-earths have been washed in the laboratory, and the minute fragments of minerals in them isolated by the use of heavy liquids. The particles thus obtained have been studied microscopically, various physical and chemical tests being applied for their identification.

The collections of materials from the washings at the mines have proved to be of great value as a means of estimating the nature of the minerals present, and (in some cases) of the relative proportions of the different minerals occurring in these alluvial deposits.

The limestones have been studied, not only by thin sections, but also by dissolving considerable quantities of them in acid, and separating the minerals left behind by the aid of heavy liquids. In this way it has been possible to determine not only the several minerals present in the calcareous masses, but also the proportions which the carbonates bear to the silicates and other minerals scattered through them.

In studying this series of rocks I have received the greatest assistance from the admirable work of LACROIX on the rocks of Ceylon and Southern India, and his comparisons of these with the pyroxene- and scapolite-rocks of other areas, such as Brittany, Central Europe, Spain, Algeria, Western Africa, Eastern Africa, Norway, Sweden, and the United States.* My studies of the rocks has also been facilitated by the receipt of numerous specimens from former students and correspondents; in particular, I may mention valuable collections obtained by me from Mr. C. BARRINGTON BROWN and Mr. P. BOSWORTH SMITH, from Ceylon and Southern India, and from the latter gentleman and from Mr. T. H. HOLLAND, of the Geological Survey of India, from the Salem district; from Mr. NASON and Professor F. D. ADAMS I have received interesting examples of the pyroxene- and scapolite-rocks of the North American Continent; while to Mr. F. R. MALLET I am indebted for specimens from South Rewah, and for much valuable information concerning several Indian localities.

In the task of working out these rocks I have been aided by several of my assistants in the Geological Laboratories of the Royal College of Science, especially by Mr. T. W. HOLLAND, F.G.S. (now of the Geological Survey of India, and the Presidency College, Calcutta); by Mr. G. W. CARD, F.G.S. (now curator of the Geological Survey Museum, Sydney, N.S.W.); and by Mr. T. BARRON. To another assistant, Mr. F. CHAPMAN, I am also especially indebted for the great skill he has shown in making microscopic sections, often from very troublesome materials.

The corundum-bearing rocks of Southern Asia appear to have a very wide distribution, and, so far as they are known, to exhibit remarkably uniform characters. The

* "Contributions à l'étude des Gneiss à Pyroxène et des Roches à Wernerite," par ALFRED LACROIX. 'Bull. de la Soc. Fr. de Mineralogie.' April, 1889. A translation of the portions of this memoir relating to Ceylon and the Salem district has been made by Mr. F. R. MALLET, and published in the 'Records of the Geological Survey of India,' vol. 24, Plate 3, pp. 155-200.

chief areas in which they have been described are Ceylon, the Salem district of the Madras presidency, the district of South Rewah in the Bengal presidency (where, in the midst of the gneiss series, beds of corundum rock are found, with others of limestone, dolomite, magnetite, and quartzite), the North-Western Himalayas, Bokara, Burma, and the Shan States of Siam.

In all these districts the rocks containing corundum appear to be highly crystalline gneisses, sometimes passing into schists, and frequently including masses of limestone and dolomite, the latter rocks being, as a rule, highly crystalline, and containing many silicates and other minerals ("calciphyres and cipollinos"). Intrusive masses of granite or pegmatite also occur. There is no evidence, so far as I am aware, opposed to the view that the whole of these rocks must be regarded as of Archæan age.

Now, as has been so well shown by LACROIX, one very remarkable and striking feature of the gneisses of Ceylon and Salem, in which districts corundum also occurs, is the prevalence of bands of granulite and gneiss of more basic composition than the rest of the surrounding metamorphic masses. These basic gneisses and granulites contain anorthite* and various forms of pyroxene, and not unfrequently scapolite, wollastonite, sillimanite (fibrolite), kyanite, andalusite, and calcite, as well as spinel, corundum, tourmaline, and other accessory minerals. As we shall have to show in the sequel, the gneiss series of Burma which yields the famous rubies contains a number of subordinate bands of these remarkable basic gneisses, composed of pyroxene, anorthite, and scapolite, with many accessory and secondary minerals; and in all their essential features these present the closest resemblances to the corundiferous rocks of Ceylon and the Salem district.

It is only in comparatively recent years that the importance and wide distribution of the pyroxene-bearing gneisses and granulites has come to be fully recognised; and there is still, unfortunately, much diversity in opinion and practice in respect to the names by which they are to be distinguished. The older writers designated them by the name of "trap-granulite," while BARROIS, following the usage of DANA and STERRY HUNT, employs the term "pyroxenite" for them. This latter term, however, as LACROIX insists, is more properly applied to rocks, either "massive" or schistose, which are almost wholly made up of pyroxenes; and the last-mentioned author describes the rocks with plagioclase felspar and wernerite as "pyroxene-gneisses" ("gneiss à pyroxène)." The Canadian geologists have called the same rocks after the predominating felspar, "anorthite-gneiss," and sometimes "augite-syenite-gneiss," or "anorthosites."

The "trap-granulites" of Saxony, which were long ago carefully studied by NAUMANN,† SCHEERER,‡ and STELZNER,§ have in recent years been made the subject

* As long ago as 1802 Count DE BOURNON pointed out the association of corundum with anorthite ("indianite") and fibrolite in the Salem district; and in 1839 G. ROSE gave the name of "barsowite" to the Ural variety of Anorthite which contains corundum.

† 'Jahrb. d. k.k. geol. Reichsanst.' (1856), vol. 7, pp. 766–771.

‡ 'Neues Jahrb. f. Min., &c.,' 1873, p. 673.

§ *Ibid.*, 1871, p. 244.

of valuable monographs by DATHE* and J. LEHMANN.† Their peculiar characters and their relations to the "flaser-gabbros" and other igneous masses which have been subjected to dynamo-metamorphic action have been rendered familiar to all geologists by the writings of these authors.

In Brittany, a compact rock of this class has long been known as furnishing materials for pre-historic weapons, and the characters and distribution of the pyroxene-bearing rocks in this area have in recent years been worked out by WHITMAN CROSS,‡ BARROIS,§ and LACROIX.||

In 1882 Professor F. BECKE gave a very careful description of the peculiar characters of the pyroxene-gneisses of the Waldviertel district in Lower Austria,¶ and pointed out the association of these with rocks containing scapolite and crystalline limestone.

Rocks of the same kind have been known for some time in Scandinavia, and have been especially studied at Oedegarden and other localities near Bamle by BRÖGGER and REUSCH,** TORNEBOHM,†† SJÖGREN,‡‡ and SVEDMARK.§§

On the North American continent, ADAMS and LAWSON|||| have called attention to the rocks of the same mineralogical composition in Canada; while their presence and wide range in the United States have been pointed out by LACROIX,¶¶ NASON,*** and others.

Areas composed of similar rocks have been described in Bavaria by GUMBEL,††† in the Pyrenees and Central France by GOUNARD and LACROIX,‡‡‡ in Spain by CALDERON,§§§ in Algeria by DELAGE,|||||| off the West Coast of Africa, opposite to the Azores, by LACROIX,¶¶¶ in South Africa (Hereroland) by WULF**** in Eastern Africa

* 'Zeitsch. d. deutsch. geol. Gesellsch.,' vol. 29 (1877), p. 274.

† 'Entstehung der altkrystallinischen Schiefergesteine' (1884).

‡ TSCHERMAK'S 'Min. und Petr. Mittheil.,' vol. 6, 1884, p. 369.

§ 'Bull. Soc. Géol. du Nord,' vol. 15, 1888, p. 69.

|| 'Compt. Rend.,' 1880, p. 1,011; and 'Bull. Soc. Min. Fr.,' vol. 12, 1889, pp. 83-361.

¶ TSCHERMAK'S 'Min. und Petr. Mittheil.,' vol. 4, 1882, p. 365.

** 'Zeitsch. d. deutsch. Geol. Gesellsch,' vol. 27, 18 5, p. 676.

†† 'Sverige Geol. Fören. i Stockholm Forh.,' vol. 5, 1882, p. 10.

‡‡ 'Sverige Geol. Fören. i Stockholm Forh.,' vol. 6, 1883, p. 447.

§§ 'Sverige Geol. Fören. i. Stockholm Forh.,' vol. 7 (1884), p. 293.

|||| 'Canadian Record of Science.'

¶¶ 'Bull. Soc. Min. Fr.,' vol. 12, 1889, pp. 267–281.

*** 'Ann. Rep. State Geologist for New Jersey for 1889,' p. 30.

††† 'Geol. Beschr. d. Ostbayer. Grenzgebirge,' vol. 2, 1868, p. 355.

‡‡‡ 'Compt. Rend.,' vol. 97, 1882, p. 1,447, and 'Bull. Soc. Min. Fr.,' vol. 6, 1883, p. 3; vol. 9, 1886, p. 46.

§§§ 'Mem. de la Com. del Mapa Geol.,' vol. 2, 1887, p. 297.

|||||| 'Géol. du Sahel d'Alger. Montpellier,' 1888, p. 149.

¶¶¶ 'Bull. Soc. Min. Fr.,' vol. 12, 1889, p. 171.

**** TSCHERMAK'S 'Min. und Pet. Mittheil.,' vol. 8, 1887, p. 193.

(Kilimanjaro) by Mügge,* in Brazil by O. Derby and Lacroix,† and in New Caledonia by Garnier and Heurteau.‡

In studying the series of gneissic rocks of Burma by the aid of the general descriptions and the specimens supplied to me by Mr. Barrington Brown, the circumstance which appears most striking is the marked difference in chemical composition between the various bed-like masses which compose it. From highly acid rock, made up of orthoclase and quartz, with a little muscovite, but no ferromagnesian silicate, we find every gradation—through normal biotite-gneisses and schists—into rocks made up of quartz, basic felspars, and pyroxenes (pyroxene-granulites, "trap-granulites," and pyroxene-gneisses); and these, by the disappearance of the felspar and quartz, pass into pyroxenites and amphibolites. The tendency of the basic felspars to break up and give rise to minerals of the scapolite family, by a process which I have described in an earlier memoir,§ and which Lacroix proposes to call "Werneritization,"‖ side by side with the change of both enstatites and augites into amphiboles, gives rise also to many interesting varieties of rocks. How far the associated limestones are to be regarded as resulting from still further alteration of the scapolite-rocks will be discussed in the sequel.

For the purpose of convenient description, we may classify the various rocks of the Burma area according to the following table:—

A. Rocks of intermediate composition forming the great bulk of the foliated masses of the district.

1. Biotite gneisses.
2. ,, granulites.
3. ,, schists.

These rocks often contain much garnet.

B. Rocks of acid composition, intercalated with the common biotite gneisses, &c.

1. Pegmatites and graphic granites.
2. Aplites and granulites ("Weissstein").
3. Granular quartzites.
4. Orthoclase-epidote rocks.

C. Rocks of basic composition intercalated with the common biotite gneisses, &c.

1. Augite (Sahlite, green diopside, &c.) gneiss.
2. Augite-granulite (with garnet, &c.).
3. Enstatite- (hypersthene) gneiss.
4. Enstatite-granulite (with garnet, &c.).

* 'Neues. Jahrb. f. Min.,' etc., vol. 4, 1886, p. 577.

† 'Bull. Soc. Min. Fr.,' vol. 12, 1889, p. 266.

‡ 'Ann. des Mines,' 6th Series, vol. 12, 1867, p. 1; *ibid.*, 7th Series, vol. 9, 1876, p. 232.

§ 'Mineralogical Magazine,' vol. 8, 1889, p. 186.

‖ 'Bull. Soc. Min. Fr.,' vol. 13, 1890, p. 35.

5. Scapolite-gneiss.
6 ,, granulite.
7. Pyroxenites.
8. Amphibolites.
9. Lapis-lazuli (Lazurite-scapolite-diopside-epidote rock).

D. Crystalline limestones intercalated in the gneisses, and usually associated with the augite- and scapolite-rocks.
Cipollinos.
Calciphyres.

E. In addition to the rocks *in situ*, we have the interesting gravels and earthy rocks formed by the atmospheric disintegration of all the other rocks.

1. *Gneiss, Granulite, and Schist.*

These rocks which constitute the great mass of the Burma area now under consideration are closely related to one another, the dominant rock is a biotite-gneiss, which passes into the other two types, granulitic and schistose, by the most insensible gradations. The minerals of which these rocks are constituted are as follows :—

1. *Quartz.*—This mineral, which is usually abundant, is often darkened, as seen in thin sections, by the very numerous bands of inclusions, containing liquids with moving bubbles, that traverse the grains in all directions Under polarized light, too, the quartz grains often show undulatory extinction and other indications of having been subjected to strain. With the quartz exhibiting these phenomena we, however, find grains—usually of smaller size—which are perfectly clear and are probably of later date than the great mass of the quartz-grains in the rock.

Felspar.—While both orthoclastic and plagioclastic felspars are present in all these rocks, the relative proportions of the two varieties varies greatly in different specimens. In the great majority of cases the felspars are somewhat cloudy, showing distinct signs of chemical alteration (kaolinization). The phenomenon that especially characterises the felspars of these rocks, however, is that known to the French petrographers as the presence of "quartz of corrosion." The grains of felspar are riddled in all directions by irregular, and often ramifying, veins of a mineral of higher refractive index than the felspar itself. Sometimes these inclusions show no trace of relationship in their position to the planes of symmetry in the crystal of felspar; but, in other cases, they clearly conform to definite directions within the crystal in which they are developed, and thus resemble "planes of schillerization." The crystals with those parallel inclusions often show very beautifully the sheen of murchisonite and moonstone. The nature and origin of some of these changes will be discussed in the chapter on Mineralogy.

Biotite.—The mica, which is approximately uniaxial, is black by reflected light and brown in thin sections by transmitted light. It occurs in irregular scales which, in some varieties of the rock, are somewhat rare, but in others very abundant. The pleochroism is intense.

$\mathfrak{c}$ and $\mathfrak{b}$, greyish and reddish-brown.
$\mathfrak{a}$, yellow to red-brown.

Absorption $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. This is so great parallel to $\mathfrak{c}$ and $\mathfrak{b}$ that the mineral appears black when traversed by rays vibrating in these directions.

While the mass of the rocks is made up of these three minerals others appear in smaller quantities.

Zircon is abundant, enclosed in all the minerals of the rock. When found in the biotite, pleochroic halos are exhibited by the latter mineral. *Apatite* is somewhat rare, as are also *magnetite* and *titanoferrite*. The latter sometimes exhibits the transformation to *sphene*, and the former to *limonite*, and occasionally into *hematite*.

Garnet (almandine) is often a very abundant accessory constituent of the rocks, and not infrequently is found undergoing change along the cracks which traverse it. In some cases the garnet is so abundant that it must be regarded as an essential constituent.

Cordierite, *sillimanite* (intergrown with biotite), *graphite*, with primary *sphene*, also occur in these rocks.

These gneissic rocks vary greatly in the coarseness of their grain. The most abundant type is a moderately coarse-grained gneiss which occasionally exhibits large "eyes," composed of quartz and felspar, and with the foliated structure fairly well-marked. In other cases, the rock is seen to be made up of more or less rounded grains of quartz and felspar, with some biotite and abundant garnets; and it may then be called a "mica granulite." On the other hand, the biotite occasionally increases in amount, while the felspar diminishes, and, the foliated structure of the rock becoming more pronounced, it approximates to a true mica-schist. Hornblende appears to occur but rarely in this series of rocks.

The greatest interest attaches however not to these gneisses themselves, but to the remarkable rocks which form subordinate members of the series, and are found interfoliated with them. Some of these are of more acid composition than the gneisses, and may be classed as pegmatites and aplites, passing into quartzites; others are of more basic composition, and include scapolite gneiss with various forms of pyroxene-gneiss, passing into pyroxenites and amphibolites. With these latter occur lazurite-diopside rocks (lapis-lazuli) and various forms of impure limestones (cipolines and calciphyres). We shall proceed to consider, firstly, the acid rocks intercalated with the gneiss series of Burma, then the basic rocks, and finally the remarkable limestones which Mr. BARRINGTON BROWN has shown to be the parent rock, both of the red corundum (rubies) and the red spinel (rubicelle or balas ruby).

2. *Acid Rocks.—"Pegmatites" and "Aplites."*

These rocks, which occur as bands in the gneiss, consist mainly of an alkali-felspar with more or less quartz and certain accessory minerals. Mr. BARRINGTON BROWN'S study of these Burma rocks in the field has led him to the same conclusion as that arrived at by Mr. F. R. MALLET in mapping the gneissic series in South Rewah *—namely, that these acid rocks are not granitic intrusions, but that they constitute an integral part of the mass of crystalline schists. Very similar rocks occur in Ceylon and in the Salem district, and have been admirably described by M. ALF. LACROIX.† We shall, however, in the sequel, have to point out some very interesting points of distinction between the Burma pegmatites and aplites, and those of Ceylon and Southern India.

The pegmatites of Burma vary very greatly in their texture. Sometimes the individual crystals of felspar are as large as a man's fist, and occasionally they attain even greater dimensions; but this coarse rock passes by insensible gradations into one of a more finely granular character, to which the name of aplite or granitell may be given. When, as is frequently the case, garnets are present, the rock passes into a true granulite or leptynite ("Weissstein" of German authors). Examples of the largely crystalline types (pegmatites) are found at several points about Mogok, at the pass leading from that place to Momeit, and many other points in the gneiss area; and fragments of them are very widely distributed in the ruby earths. The more finely granular varieties appear to have an equally wide distribution; very interesting examples of this type are found at Mandalay hill—some of them being stained of reddish and greenish tints by alteration products.

The "pegmatites" often, but not invariably, exhibit traces of the graphic structure, and sometimes pass into true graphic granites. The finer grained rocks ("aplites") usually exhibit a more or less distinct granulitic structure.

The proportions of the several mineral constituents in these acid rocks are not less variable than their texture and structure. As a rule, the felspar greatly predominates, and the quartz and mica are quite subordinate, the latter mineral being not unfrequently altogether absent. When the quartz is present in small quantities, it is usually found only as scattered grains enclosed in the felspar; when the quartz is present in larger quantities, it occurs intergrown with the felspar, to form a true graphic granite. Occasionally both quartz and mica are present in considerable quantities, and the rock becomes a typical muscovite granite, or rather granitic gneisss.

The characters presented by the constituent minerals of these rocks are as follows:—

The felspar is an *Orthoclase*, which is nearly always of a white colour. Though it frequently exhibits, in its undulatory extinction, evidence of having been subjected to mechanical stresses, yet it seldom or never exhibits the microcline structure. In

* 'Manual of the Geology of India,' vol. 1, p. 21.

† 'Bull. de la Soc. Fr. de Mineralogie.' 1889.

this respect the Burma pegmatites appear to offer a striking contrast to those of Ceylon and Salem, in which microcline is the predominant felspar while plagioclase (oligoclase) is often present also. The last-named mineral is but seldom found in the Burma pegmatites.

These orthoclases in the Burma pegmatites are not only remarkable for exhibiting the structure described by French petrographers as "quartz of corrosion," but for other peculiarities some of which will be noticed in the chapter on Mineralogy. The illustrations of the production of various kinds of schiller structure and of the alterations resulting in the play of colours characteristic of moonstone are of a very interesting character.

All these structures in the orthoclase felspars are doubtless due to incipient alteration; and in the fragments derived from these rocks, and included in the "ruby-earth," we find these changes carried out to their fullest extent, the orthoclase being sometimes converted into a kaolin, not unfrequently into a hydrous potash-mica (damourite or gilbertite) and at other times into an epidote.

Epidote is often found developed along the cracks of these orthoclases, and in one instance (viz., in a specimen collected on the road between Mogok and Momeit), the epidote has the peculiar colour and pleochroism of withamite, due, no doubt, to the fact that it contains some manganese. In another case the epidote and felspar are found so curiously intergrown as to give rise to a structure, which, when seen upon the weathered surface of the rock, was thought to be of organic origin.

The phenomena exhibited by these orthoclases in the various stages of their decomposition are of a very interesting kind and are worthy of the most careful study. In the ruby-earth, the orthoclase exhibiting the last stages of the alteration of the mineral is found, the masses crumbling between the fingers into a powder of kaolinite, muscovite, &c.

The *quartz* in these pegmatites is of the same kind as that seen in the accompanying gneisses, and is usually full of bands of inclusions; perfectly clear quartz, probably of secondary origin, also occurs in them however.

The *mica* is almost always a biaxial one—muscovite or damourite. Occasionally, however, biotite occurs, and these biotite rocks form a link between the pegmatites and the ordinary gneisses of the district.

Among the accessory minerals, fibrolite (which is often enclosed in the orthoclase), garnet (almandine), zircon, and cordierite most frequently occur. Plagioclase felspar, as has been already pointed out, is comparatively rare in them.

By the reduction in size of the grain of these pegmatites and a replacement of the graphic by the granulitic habit, the pegmatites pass into the aplites. These usually consist almost entirely of quartz and orthoclase in more or less rounded granules. Occasionally, as at Ingouk, near Bernardmyo, a rock of this class is found in which the quartz predominates over the orthoclase to such an extent that it passes in places into a granular quartzite. The only mineral which it contains, besides quartz, and traces of orthoclase, being a little muscovite and grains of zircon. In an old Hmyaudwin, near Momeit-road pass, fragments of a similar rock are found, passing into a quartz-schist by the increase of muscovite, and containing also grains of graphite.

At Nyoungouk an aplite is found, containing a felspar with a structure like that of anorthoclase (cryptoperthite), some quartz, a little plagioclase and a blue tourmaline (indicolite), showing a beautiful zoned structure, and in places passing into pink tourmaline (rubellite). See Plate 6, fig. 8.

At Mandalay Hill the aplite, which contains both orthoclase and plagioclase felspar with quartz, is sometimes changed to a greenish colour by the development of ferromagnesian silicates (epidote and chlorite ?) and at other times acquires a pinkish tint by the development of scales of hematite from the included magnetite. This rock also contains corundum (sapphire).

When these finer-grained (aplite) rocks contain, as they frequently do, garnets (almandine) they assume all the characters of ordinary granulites or leptynites ("Weissstein" of the Germans). A rock of this class is found at Yenee River Falls, near Mogok, in which the pale-red garnets exhibit anomalous double refraction; in this rock too, the beautiful green chrome-mica (fuchsite) is found. A few grains of brown biotite are not rare in some of these aplites and granulites, which thus graduate into the ordinary biotite-gneisses of the district. A very good example of one of these rocks constituting a transition between the aplites and the ordinary biotite gneisses is found between Mogok and Momeit.

In their general characters these foliated pegmatites and aplites, intercalated among the biotite-gneisses, present a very close analogy with the massive pegmatites and aplites that occur as the so-called "contemporaneous" or "segregation" veins in so many of the eruptive granites.

There are numerous examples of rocks, transitional in character, between these acid types and the normal gneisses of the district. Thus, at Letnytaung Mountain, we find a rock rich in plagioclase,—which forms large crystals, just as in the pegmatites,—with much brown mica and a dark brown hornblende. This hornblende is remarkable for its intense pleochroism, the scheme of pleochroism and absorption being as follows:—

$\mathfrak{a}$. Yellowish-brown.
$\mathfrak{b}$. Very dark greenish-brown.
$\mathfrak{c}$. Intensely dark brownish-green.

$\mathfrak{c} = \mathfrak{b} > \mathfrak{a}$.

There is a very striking resemblance between the pleochroism absorption, extinction angle, and double refraction between this variety of hornblende found in the basic gneisses and the well-known "basaltin" or basaltic hornblende found in basic lavas. This rock also contains a considerable amount of titanoferrite, passing by alteration into leucoxene (secondary sphene).

On a ridge near this same mountain there occurs a very similar rock, containing orthoclase and some plagioclase felspar, the brown hornblende, and a little biotite. The great point of interest about this rock, however, is the circumstance that both scapolite and a large amount of calcite have been developed in it, apparently at the expense of a lime-felspar (see fig. 17, p. 203).

Similar rocks, intermediate in character between the acid rocks and the normal gneisses, are found as fragments in the ruby-gravels. Thus, in the Hmyaudwin No. 15*a*, at Mogok, a specimen of a pegmatite or very coarse gneiss was found which contains orthoclase crystals, sometimes including patches of plagioclase, and tufts of fibrolite needles; plagioclase felspar sometimes passing into scapolite; an abundance of a dark brown biotite, which is sensibly biaxial but with a small angle between the optic axes; and a few grains of a pale-green augite (sahlite) exhibiting twin lamellæ.

3. *Basic Rocks.—Pyroxene- and Scapolite-Gneisses and Granulites, Pyroxenites, &c.*

It is in the more basic rocks associated with the gneissic series in Burma, with their closely associated crystalline limestones, that the chief interest of the geologist is centred; for it is undoubtedly in connexion with these rocks that the rubies, spinels, and other gem-minerals are found. These rocks contain, in addition to a lime-felspar (anorthite or labradorite), several varieties of pyroxene (white and green diopside, sahlite, and hypersthene), which may be replaced by hornblende or biotite, and in many cases a considerable quantity of scapolite, wollastonite, and calcite.

Rocks of this class occur in bands which are subordinate to the gneiss of the district, and are common both in the Mogok valley and in the Injouk valley. Thicker masses of the same rock are found intercalated in the gneisses on the ridge between Mogok and Bernardmyo. The frequency of fragments of these rocks in the ruby-bearing gravels testifies to their very wide distribution.

The rocks present a characteristic dark greenish-grey colour, often accompanied by a greasy lustre, and are thus easily distinguished from the ordinary gneisses with which they are associated.

The coarser grained rocks of this class may be distinguished as *pyroxene-gneisses*, or as *pyroxene-scapolite-gneisses*, when the latter mineral is largely developed in them. These rocks appear to the eye as coarse aggregates of a grey felspar (anorthite, or a variety like bytownite) and a black or very dark-green augite, and various accessory minerals, among which sphene is the most abundant and conspicuous.

Very coarse varieties of these pyroxene gneisses occur as fragments in the Hmyaudwins No. 3, at Mogok, and No. 27, in the Kyatpyen districts; the rocks have suffered somewhat from atmospheric disintegration, but their essential characteristics can be made out in thin sections under the microscope.

The felspars exhibit lamellar twinning in a very local manner, the lamellæ dying out in certain portions of the crystals, and large areas of the latter being altogether free from lamellar structure. The extinctions of these lamellæ point to their being a variety rich in lime, and this conclusion is confirmed by micro-chemical examination of fragments. The felspars often betray traces of much alteration, and not unfrequently exhibit both opalescence and the rich play of colours so common in labradorite. Schillerization is frequently displayed, and the so-called "quartz of corrosion" is very common in them.

Some of the felspars in these pyroxene gneisses are converted wholly or partially into scapolite, and numerous beautiful examples of the manner in which this change takes place may be found. As I have shown to be the case at Bamle, the conversion of the lime-felspar into scapolite (dipyre) appears to be a deep-seated one and to be one of the results of the dynamo-metamorphic action to which these rocks have been subjected. The scapolite itself often shows the first signs of chemical alteration and becomes cloudy in ordinary light, while with the polariscope the colours due to double refraction are patchy and variable.

The pyroxene in these rocks is an augite very variable in colour, as seen by transmitted light, and forms crystals up to two centimetres in length. Sometimes it is of a rich dark green, at other times of a very pale green, becoming occasionally quite colourless. Whenever any colour can be distinguished, a *very faint* pleochroism can also be detected, the colours being a bluer green for the rays traversing the crystal parallel to the $\mathfrak{a}$ axis, and a yellower green for the rays parallel to $\mathfrak{b}$ and $\mathfrak{c}$. The absorption is so slight that I could not satisfy myself as to the direction in which it is greatest. This pyroxene often shows the beginning of alteration, ferruginous staining appearing along the cracks of the crystal. Schiller enclosures also appear in it parallel to both the orthopinacoid (100) and the basal plane (001). The augite also shows the beginning of uralitization, the development of the hornblende being accompanied by a separation of magnetite, which renders the mineral almost opaque.

Sphene is present in some of these rocks to almost as great an extent as the augite, and in this respect the Burma rock strongly resembles the well-known augite-felspar-sphene rock of Bamle. The sphene occurs in two forms. In the first place, we have the large wedge-shaped crystals from 5 to 10 millims. in length, of a yellowish-brown colour with slight but distinct pleochroism :—

$\mathfrak{a}$, very pale yellow,
$\mathfrak{b}$, greenish-yellow,
$\mathfrak{c}$, reddish-yellow.

Not unfrequently this brown sphene shows signs of alteration. Along the cleavage-cracks, especially on the outside of the crystals, black opaque deposits of ilmenite are seen, and this is sometimes accompanied by the formation of the white opaque material, so commonly observed when titanoferrite is undergoing decomposition. On the other hand, we find a number of smaller grains of the perfectly colourless sphene (leucoxene or titanomorphite) which is so frequently found resulting from the alteration of titanoferrite. It seems probable that in this rock we have examples of both kinds of paramorphism between ilmenite and sphene. The original coloured sphene is seen passing through a white opaque compound into titanoferrite; and on the other hand a colourless sphene occurs which is probably of secondary origin and results from an alteration of the titanoferrite which originally formed a constituent of the rock.

The other accessory constituents of these interesting pyroxene gneisses are apatite, which is found enclosed in all the other minerals of the rock, zircon, which is abundant, and occasionally corundum. The existence of this mineral in these peculiar basic gneisses is a very interesting and, as we shall hereafter show, a very significant fact.

Some of the chief types of these pyroxene gneisses are illustrated in figs. 15, 16, and 17, and in Plate 6, fig. 1.

Rocks of similar mineralogical constitution to these coarse pyroxene-gneisses, but of finer texture and assuming a more or less perfect granulitic habit, appear to be by no means rare in Burma. They exhibit a great diversity in the characters of their constituent minerals, but nearly all consist of a lime- or lime-soda-felspar (more or less altered to scapolite and sometimes to calcite and quartz) and a pyroxene which may be some form either of enstatite or augite, or may be partially or wholly converted into a hornblende or a biotite. These rocks may be designated pyroxene-granulites and pyroxene-scapolite granulites, and I will proceed to describe some of their most interesting varieties.*

On the ridge below Toungnee a rock was found *in situ*, which proves on microscopic study to be a *sahlite-scapolite-granulite* (see Plate 6, fig. 3). In this rock a white augite (sahlite) is very abundant and constitutes not less than one half of the mass. The mineral seen in thin sections shows no trace of colour or pleochroism, it has the usual augite cleavages, but no trace of schiller planes, and its extinction-angle is low—apparently not exceeding 40°. With the augite a few grains of an enstatite (bronzite) also occur. The remainder of the rock is almost entirely made up of a scapolite often exhibiting traces of the commencement of decomposition. There is no distinct felspar found in the rock, but the scapolite not unfrequently shows, by the relics of a lamellar structure in it, that it has been produced by the alteration of a plagioclase. Zircons are found enclosed in all the other minerals, and a few garnets and crystals of sphene with corundum (?) are among the accessory minerals of this very interesting rock.

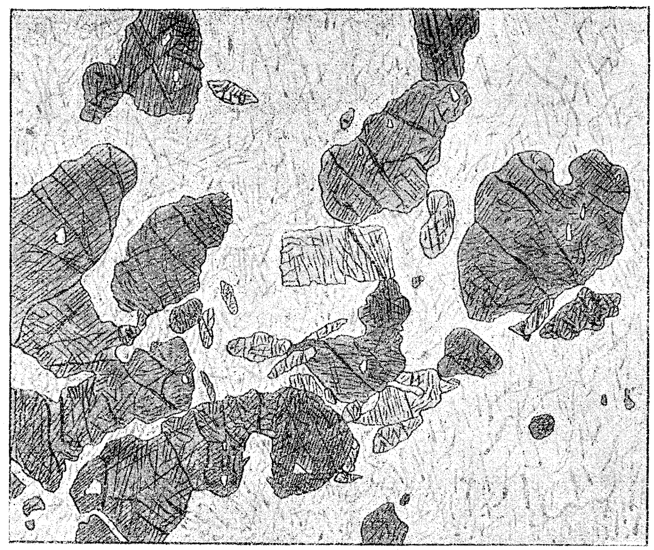
A rock closely related to the last is found at Letnytaung mountain. It is an *augite-scapolite-granulite* (see Plate 6, fig. 2) and consists of the following minerals :— A dark-coloured augite, exhibiting in thin sections the purplish tints of the varieties of this mineral containing titanium, but with scarcely a trace of pleochroism, constitutes more than one-third of the rock; the remainder of the rock is made up of

* The interesting rock recently described by Mr. T. H. HOLLAND as "charnockite," or hypersthene granite, is a massive rock of similar composition, but rich in orthoclase.

scapolite, which has clearly been derived from a plagioclase felspar, quartz, some of which is quite free from bands of inclusions and is probably secondary, and calcite, grains of which are by no means rare; the accessory minerals are garnet, sphene, and zircon.

On the road from Mogok to Momeit a rock occurs *in situ* which contains a white augite (sahlite or malacolite), a ferriferous enstatite (hypersthene), and a little biotite with some magnetite or titanoferrite in large grains (see Plate 6, fig. 4). The white augite is similar to that found at Toungnee, and the hypersthene shows the usual pleochroism of an enstatite moderately ferriferous. The remainder of the rock is almost wholly made up of grains of scapolite, some of which show, however, in the

Fig. 15.



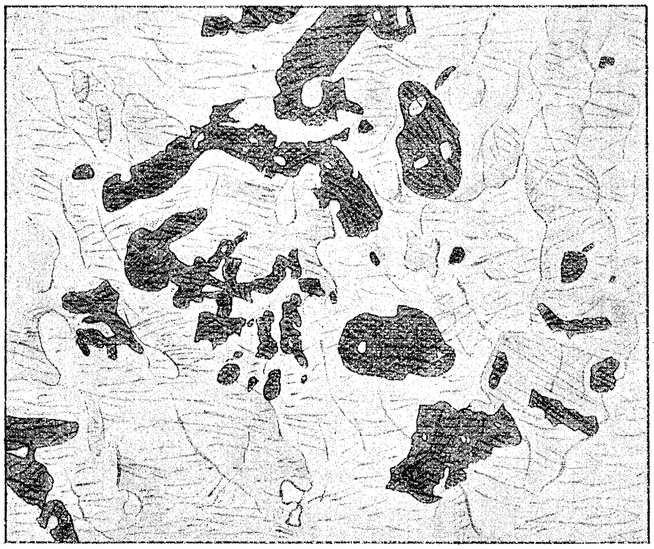
Pyroxene-gneiss, from Mogok. × 3 diameters. The dark crystals are a pale-green augite. The paler crystals a yellowish-brown sphene, and the rest of the slide is made up of a basic felspar near anorthite, which, in this instance, has undergone but little change.

presence of faint traces of lamellar structure that they have been produced by the alteration of a plagioclase. The brown biotite of this rock appears to have been formed by the alteration of the sahlite.

A variety of the sahlite-granulite rock from Toungnee hill is interesting as exhibiting the alteration of the white augite into brown biotite and the plagioclase felspar into scapolite. Every stage of these interesting changes may be traced in this particular rock, which also contains a considerable quantity of hypersthene.

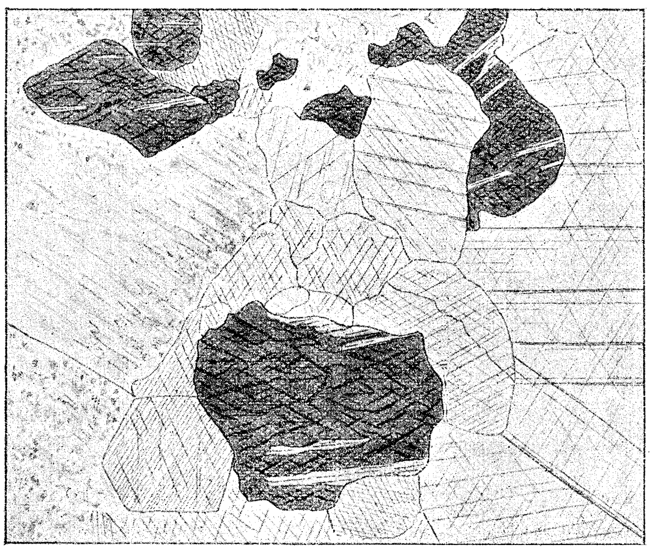
Near the cantonments at Bernardmyo there occurs a coarser grained variety of these rocks, distinguished by the limited amount of ferro-magnesian silicates and the presence of orthoclase. The augite of this rock is largely altered to hornblende and biotite. In No. 13 Hmyaudwin at Mogok a very similar rock (see Plate 6, fig. 1)

Fig. 16.



Pyroxene-scapolite-gneiss from Mogok. × 3 diameters. Very dark-green pleochroic crystals of augite, are seen scattered through a mass of felspar and scapolite crystals, the latter being so full of inclusions as to show an opalescence like that of "moonstone." In ordinary light the scapolite is distinguished from the felspar by its slightly darker tint.

Fig. 17.



Hornblende-biotite gneiss passing into a caciphyre, from the ridge near Letnytaung × 6 diameters. The dark crystals are deep brown hornblende, with intergrowths of biotite. On the left we have somewhat decomposed plagioclase felspar, while over the rest of the slide calcite prevails.

occurs in fragments in the ruby gravels, but this rock contains hypersthene as well as augite.

Pyroxene-granulites, with both augite and enstatite (hypersthene) and the plagioclase felspar more or less completely altered to scapolite, occur, by no means rarely, in the ruby gravels, as at the Hmyaudwins Nos. 9 (see Plate 6, fig. 6) and 13 at Mogok. In many cases, however, the pyroxenes are more or less completely altered into hornblende and biotite. In one case I have found the augite changed to the schillerized forms—diallage and pseudo-hypersthene.

While some of the pyroxene-gneisses are rich in felspar and contain some orthoclase, others are remarkable for the abundance of the ferro-magnesian silicates, and when all the alumino-alkaline silicates disappear, these rocks pass into the pyroxenites, or by alteration into amphibolites. These rocks consist of an augite, sometimes nearly colourless, at other times green, and occasionally purplish in tint, and more or less hornblende, evidently formed by the alteration of the pyroxene. Enstatite (hypersthene or bronzite) is also sometimes present. The colourless minerals—plagioclase in various stages of Werneritization—and quartz and calcite are so rare that they can only be regarded as accessory. In addition we find sphene, both original and secondary (titanomorphite), apatite and titanoferrite.

At the mine No. 14 at Mogok there occurred a rock of this kind, consisting of nearly equal parts of a purplish-brown augite and a deep-brown hornblende, very similar to basaltine (basaltic hornblende). There are clear indications that the hornblende is paramorphic after the augite. In this case only minute and inconsiderable quantities of the white minerals (felspar, quartz, calcite, and scapolite) are present.

In a Loodwin, near the Momeit-Road Pass, a rock consisting of a dark-green augite, occasionally changed to a brown hornblende, is found. The rock also contains some wollastonite, and is interesting, as it is seen to be interfoliated with a crystalline limestone, the one rock passing insensibly into the other.

At the pass from Kyatpyen into the next valley to the west, there is a rock which seems to have originally consisted of a colourless augite with some brown sphene. The greater part of the augite has now been converted into a brown hornblende, and the pyroxenite has been converted into an amphibolite.

The connection between these rocks, so rich in ferro-magnesian silicates ("ultrabasic gneisses") and the calcareous rocks is often of the most intimate kind.

The last of these basic rocks which we have to notice are those which contain the beautiful blue minerals—coloured by a sulphur compound—hauyn and lazurite (lasurit of Brögger). The blue crystals are isotropic, and vary greatly in the intensity of their tints, consisting in all probability of haüyne, and perhaps sodalite, as well as lazurite. The blue mineral is accompanied by a colourless pyroxene (diopside), with calcite, scapolite, epidote, and other colourless minerals, the whole forming a very beautiful lapis-lazuli rock. (See Plate 6, fig. 9.)

There are two varieties of this rock. In one the blue isotropic minerals do not form more than one-third of the mass, the remainder consisting of granules of white diopside, with a very fine ground mass, consisting largely of alteration products like scapolite and calcite.

In the other variety, the blue minerals (which vary in tint from an intense violet-blue to a pale lavender-blue), make up more than two-thirds of the whole, but enclose a number of granules of the white diopside, with some patches of decomposition products.

Although these beautiful lapis-lazuli rocks have not been detected *in situ*, their presence in the ruby-gravels with rocks that have all clearly been derived from the disintegration of the gneiss of the Burma area, shows that they must occur as members of this gneiss series. The specimens examined and described were found near Thabanpin. Different varieties of the rock are shown, by determinations made by Mr. T. BARRON, to vary in specific gravity from 2·86 to 2·94.

4. *Crystalline Limestones.*

As has been already pointed out, the connection of these calcareous rocks with the gneissic rocks among which they are intercalated, is of the most intimate character. With the basic pyroxene and scapolite-rocks, and especially with the pyroxenites and amphibolites into which these graduate, the calcareous rocks appear to be always closely associated.

The idea that great beds of crystalline limestone, intercalated in a series of foliated rocks, must necessarily have resulted from the metamorphism of calcareous strata of organic origin, which have alternated with other aqueous or igneous masses, finds no support from the characters presented by the rocks of Burma.

Between gneissic rocks containing numerous crystals of calcite and dolomite, and rocks consisting mainly of those minerals, with the various constituents of the basic gneisses—augites, enstatites, scapolites, phlogopites, &c.—scattered through them, we find every gradation, and the limestones and gneisses are also found interfoliated in the most intimate manner.

That some impure crystalline limestones (hemithrènes, kalkaphanites, &c.) have been formed from basic igneous rocks, there is not the smallest doubt,* and in the same manner the study of the Burma limestones leads to the conclusion that the basic gneisses may undergo a corresponding metamorphosis, the breaking up of the lime-felspars leading to the formation of an unstable scapolite, from which and from other unstable minerals originate, as a consequence of further change, the calcite and dolomite; while the more stable silicates become enclosed in the crystallizing mass of carbonates, and new minerals are formed during the progress of these complicated chemical actions.

The capricious manner in which the gneisses and calcareous rocks of Burma are

* See Liebrich, 'Neues Jahrb. für Min.,' &c., for 1893, Bd. 2, p. 75.

associated, and the unexpected manner in which the one type of rock seems to replace the other, has been illustrated by Mr. BARRINGTON BROWN in his account of their relations as seen in the field.

In their general appearance and texture these metamorphic limestones of Burma exhibit the widest diversity. Sometimes, as in the bands that occur at Bernardmyo, they are finely granular (saccharoid) in character ; at other times, as is well exemplified in the ruby-cave at Mogok, the individual crystals of calcite may grow to the size of a man's fist. There are few more beautiful limestones than this rock of Mogok, with its delicate blue tint and the large and brilliant cleavage-faces of its twinned calcite crystals.

The crystalline limestones of Burma also differ greatly from one another in the proportions and the nature of the minerals enclosed in them. Some of the limestones are almost free from foreign minerals, while others are made up to the extent of more than half their mass of various silicates, oxides, and sulphides.

Many of the limestones contain a notable proportion of dolomite. Sometimes the dolomite grains are of the same size as those of calcite, with which they are intergrown, and only differ from them by the comparative rarity of twins following the $-\frac{1}{2}R$ (110) planes of the crystal and their insensibility to the action of cold dilute acids. In other cases, however, the dolomite in these limestones make up aggregates of minute rhombs, which are left behind when the rock is digested with acetic acid or with dilute hydrochloric acid in the cold, but are rapidly dissolved in boiling acid.

We may group these crystalline limestones into two classes according to the nature of the foreign minerals that are present in them, as follows :—

(1.) *Cipollinos*, in which the predominant foreign constituent is a micaceous mineral, and the rock usually exhibits a more or less distinctly foliated structure, thus passing into a calc-schist (kalkschiefer). Rocks of this class occur at Mandalay Hill and on the Mogok side of the pass on the Bernardmyo road, near Toungnee mountain, and many other localities too numerous to specify. Similar limestones are very common as fragments in the various pits opened in the alluvial deposits for obtaining rubies.

(2.) *Calciphyres.*—This old name of BRONGNIART's may be conveniently applied to the rocks, consisting of a ground mass of calcite crystals, through which various pyroxenes and other minerals are distributed like porphyritic constituents. The well-known red limestone of Ballyphetrich (Tiree marble) was made by BRONGNIART the type of his Calciphyres, and there are many interesting points of resemblance between the Hebridean limestone and the very beautiful rocks of the same class in Burma.

The minerals that have been found in these Burma limestones are very numerous. They may be conveniently divided into two classes as follows :—

(*a*.) Minerals which are identical with those found in the associated basic gneisses, pyroxenites, and amphibolites.

(*b.*) Minerals which occur in the limestones, but have not been found in the masses with which the limestones are interfoliated.

There are a few minerals (which must be relegated to a third group, as they occur rarely in the pyroxene-gneisses and pyroxenites, but are much more abundant in the limestones.

Belonging to the class (*a*) are the following species :—

Diopside (white and pale-green).
Bright-green augite.
Purplish-brown augite, passing into diallage and pseudo-hypersthene.
Sahlite (white, aluminous augite.)
Enstatite.
Bronzite.
Hypersthene.
Quartz.
Orthoclase (Murchisonite and Moonstone).
Oligoclase.
Anorthite.
Hornblende (a variety near Basaltic Hornblende).
Biotite and other micas, including Fuchsite.
Scapolite.
Zircon.
Magnetite.
Titanoferrite.
Sphene (both original and secondary).
Rutile (in inclusions).
Garnet (almandine).

(*b.*) Among the minerals which especially characterize the limestones are the following :—

Phlogopite (changing to vermiculites).
Wollastonite.
Corundum (ruby).
Spinel.
Pyrrhotite.
Diaspore.
Hematite.
Limonite.
Apatite (Moroxite.)
Graphite.

The minerals which occur in the gneisses but have not certainly been detected in the limestones are :—

Tourmaline (Rubellite, Indicolite, &c.).

The results obtained by separating the silicates from the carbonates by the action of dilute hydrochloric acid in the case of the beautiful blue limestone from the ruby cave of Burma, were as follows :—The proportion of insoluble residue was found to vary in different cases from 2 per cent. to 3·34 per cent. The amount of insoluble minerals in a number of average fragments, weighing together 688·46 grammes, was 21·23 grammes. This gives a percentage of 3·17, which is probably near a true average. The limestone of the Burma ruby cave is a pure calcite, almost wholly free from dolomite.

5. *Gravels and Earthy Deposits.*

These deposits are made up entirely of fragments of the rocks found *in situ.* The fragments are sometimes all angular or sub-angular ; but well-rounded water-worn pebbles are by no means unfrequent in them. The fine materials of the earths consist of scales of kaolinite, mica, &c., stained to a yellowish-brown tint by ochreaceous material. J. W. J.

VII. Mineralogy.

In studying the series of minerals obtained from the interesting corundiferous localities of Burma, there are three classes of facts which appear to have a special significance and to be worthy of study for their important scientific bearings.

First. The association of the various species of minerals in the rocks of Burma, which contain the rubies and other gems; and the comparison of this association with the facts observed in other areas, where the same gems occur. This study of paragenesis constitutes a line of enquiry of great promise to the mineralogist.

Secondly. This association of minerals in particular rocks of different areas is suggestive of the conditions under which the Burma gems—the corundum (ruby), spinel and tourmaline (rubellite)—may have been formed, and the chemical reactions to which they owe their origin.

Thirdly. Not less interesting than the question of the origin of the ruby and its associated gems, are the problems concerning their alteration and destruction, which, as we shall show, have been continually going on, as the result of both deep-seated and surface action.

1. *Association of Minerals in the Gem-localities of Burma.*

The investigations of Mr. C. Barrington Brown have shown that the parent rock of the famous rubies of Burma (the "pigeon's-blood rubies") is undoubtedly a highly crystalline limestone which encloses crystals of corundum, spinel, pyrrhotite, graphite, phogopite, and many other minerals. Equally decisive is the evidence that he has brought forward to show that the fine red tourmalines (rubellites) of the same district in Burma do not occur in these limestones in association with the rubies and spinels, but come from another locality, their parent rock being a gneiss or schist. The significance of these facts will become apparent when we consider the association of minerals at other localities where corundum is found in limestone, as at St. Gothard, in Switzerland, and in the limestone belt of Orange Co., N.Y., and Sussex Co., N.J., in the United States.

There are two kinds of evidence which are available in determining the nature of the minerals associated with the ruby and spinel in Burma. The first and most satisfactory is derived from examination of the limestones which contain the gems. This may be done either by means of thin sections, or by dissolving the limestone in acid and separating and determining the various insoluble minerals left behind. Nature, however, has done this latter kind of work for us on a grand scale, and in the alluvial deposits we find great accumulations of the insoluble minerals which were originally embedded in the limestone, and here we naturally obtain larger and finer crystals than we can hope to procure by carrying on the work of solution in the laboratory. It must not be forgotten, however, that there is an element of uncertainty in the evidence afforded by these alluvial deposits, as some of the minerals found in them may be derived, not from the corundiferous limestones, but from other associated rocks in the district; hence it will not be wise to accept the evidence afforded by the alluvial deposits, unless it is corroborated by the fact of the same minerals being actually found in the limestone or in the residues obtained by its solution.

In the following list are included all the species of minerals which I have been able to determine in the crystalline limestone of Mogok and the surrounding districts and in the granular limestone of Sagyin. In the remarks about the several minerals I have, however, often availed myself of information derived from the study of the finer and larger specimens yielded by the alluvial deposits.

1. *Corundum.*—This mineral rarely presents crystalline outlines, for, as we shall presently see, chemical disintegration and alteration into diaspore and various silicates has gone on from the exterior, and the core of unaltered aluminium oxide left behind is of irregular form. Occasionally, however, well defined crystals of corundum are obtained, and it is a noteworthy circumstance that, as has been already pointed out by Mr. F. R. MALLET, the Burma rubies generally assume peculiar and characteristic combinations of forms.* Crystals made up of the rhombohedron and basal plane (R and 0R : 111, 100) are very common, though the prism (∞ P2, $10\bar{1}$) occasionally enters into the combination. Forms in which the prism and pyramids (so constantly seen in the corundums from Ceylon, Southern India, United States, &c.) are found predominating, are, so far as my observation goes, very rare; though several such combinations are figured by Mr. MALLET.

The forms present in the ruby-crystals of Burma are thus seen to be the same as those found in the artificial rubies made by MM. FRÉMY and FEIL; but in the arti-

* 'A Manual of the Geology of India,' Part IV., Mineralogy (1887), p. 43, Plate 1, figs. 6, 7, 8.

ficial crystals the degree of development of the basal plane (0R) is usually much greater, and the crystals thus come to assume a tabular character.

In order to obtain the specific gravity of the Burma rubies, a selection of clear finely coloured gems was made from the washings brought from Burma by Mr. BARRINGTON BROWN, and their density was determined by the pycnometer. The average density of the Burmese gem was found to be 4·03. DE BOURNON found the average density of twenty rubies, of which the locality is not stated, to be 3·98. Most of the associated red corundums of Burma have a considerably lower density, and in the case of one crystal, showing marked indications of chemical change, it was found to be as low as 3·74.

The colours of the Burma corundums are very variable. Every shade from white through various shades of pink up to the deep crimson (pigeon's-blood colour), which is so highly prized, may be found. The stones are not unfrequently parti-coloured, and variable in tint in different portions. Mr. BARRINGTON BROWN brought home a remarkable specimen, which was colourless at one end and graduated at the other end into the most beautiful and intense red. All the coloured varieties of corundum occur, but in much smaller quantities than the red ones; blue of every depth of tint (sapphires), yellow (oriental topaz), purple (oriental amethyst) are not rare; but the green varieties (oriental emerald, oriental chrysolite, and oriental aquamarines) with the colourless ones (white sapphires) appear to be of very exceptional occurrence.

The pleochroism of the Burma rubies of course varies with their colour, but there seem to be constant peculiarities in the pleochroism of gems of different districts which can be detected by the aid of the dichroiscope. Thus the sapphires of Burma, like those of Ceylon, show tints of blue and *straw-colour* with the dichroiscope, while the Siam sapphires give blue and a decided *green* colour. In the same way, while the fine rubies of Burma give crimson and *aurora-red* tints for the ordinary and extraordinary ray respectively, the less finely coloured stones from Siam give crimson and a *brownish-red* tint for the two rays.

The Burma rubies not unfrequently exhibit cavities, sometimes of considerable size, and often of very irregular form. These cavities sometimes contain a liquid and bubble (carbon dioxide), but in other cases appear to be filled with solid matter—a reddish-brown glass in some instances. Not unfrequently we find the rubies filled with acicular or platy inclusions arranged along the rhombohedral planes and intersecting one another at angles of 60°. These give rise to the beautiful phenomenon of asterism. In some cases, a well-marked zoned structure is exhibited by crystals, in which layers filled with inclusions, and giving a striking "schiller," alternate with clear bands without inclusions. A remarkable example of this kind is in the possession of Mr. STREETER.

In the great majority of cases the Burma rubies exhibit a perfectly irregular or conchoidal fracture, like that of quartz. Chemical alteration sometimes leads to the formation of a secondary parting along the basal plane, while still more rarely the familiar gliding planes following the primitive rhombohedron have been developed by pressure and intensified by subsequent chemical change.

The clear and brilliantly coloured rubies seldom, if ever, attain to great dimensions, either in the Burma limestones or in the alluvia; but masses of red corundum are occasionally found weighing several pounds. [Occasionally specimens are found showing a perfect transition from the dull red crystalline corundum into the transparent and lustrous ruby. I am indebted to the Burma-Ruby-Mining Company for a beautiful illustration of this transition.—November 30, 1895.]

2. *Spinels.*—In the beauty of their colour and lustre the spinels found in the Burma limestones are scarcely inferior to the corundums, but they are of course wanting in that play of colour which results from the possession of the property of pleochroism. They more frequently exhibit their proper crystalline form—the octahedron without modifications—than do the corundums; but twinned forms appear to be rare. Various tints of red are the most common colours, specimens from the palest pink to the deepest crimson being found. The average specific gravity of these red spinels, determined on a number of carefully selected examples, was 3·52. With the red spinels, however, there occur more rarely various shades of blue, violet, brownish, and occasionally black (ceylanite). The faces usually exhibit etched figures, and, as we shall see in the sequel, alteration forms of the mineral are very abundant. The fracture is almost always conchoidal, and only rarely do we find traces of the parting (probably of secondary origin) parallel to the octahedral faces.

The proportion of spinel to corundum, at different localities in Burma, appears to vary to a very marked extent. At Sagyin, spinels are very abundant, and rubies comparatively rare, while in the limestone of Mogok, the red corundum abounds and the spinels are in nothing like such great excess. In a mass of gems brought home from a twinlone at Mogok, by Mr. BARRINGTON BROWN, I found that the spinels weighed 54·39 grams, or 64 per cent. of the whole, and the corundums 30·33 grams, or 36 per cent. All the spinels from this pit were various shades of red, with the exception of 0·39 gram of shades of blue spinel. Among the corundums, 25·87 grams were various shades of red, 1·20 grams were blue (sapphire), 2·57 were yellow (oriental topaz), and 0·69 purple (oriental amethyst).

A prospecting pit, sunk by Mr. BARRINGTON BROWN at Bernardmyo, yielded, however, very different results. The washing of about two cubic yards of earth yielded 76·71 grams gems, in which I found 63·89 grams, or 83 per cent., of spinels, mostly red, and 12·82 grams, or 17 per cent., of corundum. The latter comprised 5·65 grams of colour and clearness, entitling them to be called "rubies," 1·26 grams of sapphire, and 6·91 grams of red corundum.

3. *Zircon* occurs but rarely in association with the corundums and spinels of Burma. Well-developed crystals are found in the washings, consisting of the combination of prism and pyramid (∞ P and P : 110, 111). These zircons are nearly colourless, have a remarkable lustre, and may easily be mistaken for diamonds. In a mass of lime-

stone brought from the ruby-cave at Mogok by Mr. BARRINGTON BROWN, there occurs a colourless crystal of high lustre with curved faces, which was naturally taken, at first sight, for a diamond. A careful measurement of the angles by Mr. H. A. MIERS, of the British Museum, however, suggested that the mineral must be zircon. Strange to say, however, when this specimen was sealed up in a vacuum-tube by Mr. CROOKES, and submitted to an electric discharge, it gave a phosphorescence very similar to that of many diamonds, and very different from that of most zircons. But an undoubted zircon from washings at Burma, when sealed up and exposed to the electric discharge, exhibited the same remarkable phosphorescence. For the application of these important tests, and much other valuable aid in the study of these minerals, I am greatly indebted to Mr. W. CROOKES, F.R.S.

4. *Garnets,* which are so abundant in the gneiss rocks that are interfoliated with the limestones, occur also in the latter rocks themselves. Almandine, andradite, and more rarely grossular garnets occur, crystals over a pound in weight being sometimes found. Like the accompanying minerals, the garnets are often found undergoing various stages of alteration; and in the gravels there are frequently found pseudomorphs of garnet crystals, which crumble to pieces when handled.

5. *Apatite* of a beautiful and unusual blue tint is found in some of the washings, mingled with the other gems. It forms well-defined crystals.

6. *Felspars* of several species, both orthoclastic and plagioclastic, abound in the washings. The orthoclase often exhibits the Murchisonite parting, with the peculiar schiller due to reflection from air films characteristic of that variety. Not unfrequently the varieties with brilliant reflections from included scales (sunstone), and those with opalescence and chatoyance (moonstones), are found. In many cases the felspar-crystals, as they occur in the washings, are completely converted into kaolin, and sometimes they are, to a greater or less extent, changed into epidote. In one case, a large felspar-crystal was found in which alteration into epidote had gone on along the two principal planes of cleavage, the result being a mass which weathered, with surfaces that suggested organic structure.

7. *Quartz* of different varieties is found in nearly all the ruby-earths. Milk-quartz, rose-quartz, and amethyst occur, but are rare, while citrine and smoky quartz are common. Many beautiful examples of parallel growths are seen, and, in the case of a fine example from a mine at Mogok, this parallel growth is accompanied by a spiral twisting of the principal axis of the crystal, resulting in forms like those of Trabecsthal, which have been lately so admirably investigated by TSCHERMAK.* Even the quartz has not escaped the alteration so universally exhibited by the minerals of these ruby-bearing rocks. We find the quartz-crystals to be, in nearly all cases, pitted all over with naturally etched figures (*Verwitterungs-figuren*), often of a very interesting character.

8. *Micas.*—Phlogopite is one of the most common constituents of the corundiferous

* 'Denks. k.k. Akad. Wissensch., Wien Math.-Naturwissensch. Cl.,' Bd. 61 (1891), p. 365.

limestones of Burma; and in the ruby-earths hexagonal plates of mica with a diameter of from 20 to 30 centims. are frequently found. These phlogopites are some clear and almost colourless, but more usually show tints from smoke-brown to black. The angle between the optic axes of these phlogopites is shown by the interference figures to be small, never exceeding 20 or 30 degrees, and is often much less. In the ruby-earth muscovite, probably an alteration product from corundum, orthoclase and other minerals are frequently found.

Fuchsite, or the beautiful green chrome-mica, certainly occurs in some of the samples of ruby-earth from Burma, and is also sometimes seen in the limestone containing rubies from Mogok (see Plate 6, fig. 10).

9. *Amphiboles* are common in the ruby-earths and the limestone, and include several varieties of both green and brown hornblende with a variety near to arfvedsonite.

10. *Pyroxenes* are particularly common, and include a nearly colourless sahlite, green diopside, and a green soda-pyroxene (ægerine), with a jade-like variety among the augites, and both bronzite and hypersthene among the enstatites; *wollastonite* is by no means rare in some of the limestones and associated rocks.

11. *Fibrolite* (sillimanite) is also a constituent of the limestones.

12. *Scapolite* is found in the limestone, but has not been detected in the ruby-earths; it has probably disappeared through alteration processes, giving rise to the formation of calcite.

13. Besides *Muscovite* and *Gilbertite*, other silicates found in these limestones, which probably represent decomposition products, are *Margarite*, and several other clintonites, and various chlorites and vermiculites.

14. *Kaolinite* (*nacrite*) is very abundant, probably derived from the felspars; and, indeed, this and similar hydrated silicates of aluminium appear to make up the bulk of the ruby-earths.

15. *Lapis-lazuli*.—Among the interesting minerals brought from the ruby-earths of Burma, are great blocks of lapis-lazuli. These are of two varieties. In one, the quantity of blue mineral is so great that the rock-masses have a deep indigo tint, the quantity of white minerals being, as seen in thin sections under the microscope, comparatively small. In the other variety we have a white mass speckled with blue. Microscopic study of these rocks shows that we have several isotropic, blue minerals present (lazurite, haüyne, sodalite) and various nearly colourless minerals, including white-diopside, wollastonite, scapolite, epidote, and calcite.

16. *Graphite*, often well crystallized, occurs in plates up to 8 or 10 centims. in diameter in the ruby-earths. It is also found to be present in almost all the limestones.

17. *Pyrrhotite*, like graphite, is among the most widely distributed of the minerals in the limestones. It appears, like graphite, to be a constant associate of the rubies and spinels.

In addition to these undoubted constituents of the Burma limestones, there are several other minerals which have been brought from Burma, but have not yet been detected in the limestones. Among these are beryl (aquamarine) and danburite.

The absence of certain minerals from the Burma limestone is very noteworthy, especially if we compare the association of minerals there with that found in other corundiferous limestones—like those of Orange County, N.Y., and Sussex County, N.J., and the well-known rock of St. Gothard. So far as my observations go, I can find no trace of the silicates with fluorine and boric acid. Neither topaz, the tourmalines, the axinites, or the chondrodites have been found, though most of these minerals are found abundantly in the corundiferous limestones of the Eastern United States and the Alps. Chondrodite has been reported as occurring in Burma limestones; but, I think, the yellow decomposition products of corundum may in some instances have been mistaken for the mineral in question.

[Since this was written, my friend, Mr. T. H. HOLLAND, F.G.S., of the Geological Survey of India, has sent me some remarkable specimens of a limestone from Sagyin, in which very fine spinels are found associated with much chondrodite. My friend, Dr. W. T. BLANFORD, informs me that a limestone of this kind also occurs just outside Mandalay. But of the occurrence of chondrodite in the Mogok limestones, I have hitherto been unable to obtain any evidence.—October 7th, 1895.]

2. *Origin of the Corundum, Spinels, and other Minerals occurring in the Limestone of Burma.*

The investigations carried on with respect to the mode of origin of the Burmese gems, which have been detailed in the preceding pages, show that the parent rock of the corundum and spinel is a limestone—either highly crystalline or saccharoidal—which contains a great variety of included minerals, silicates, and oxides, with graphite and pyrrhotite. The limestone which the rock of Burma most closely resembles is undoubtedly that of Orange County, N.Y., and Sussex County, N.J., which are associated with the remarkable deposits of zinc ore at Franklin Furnace and Ogdensburg, N.J. In comparing the minerals found in these limestones of North America, as given by Mr. J. F. KEMP,* and those of Burma, we shall be struck by the large number of species in common. But there is one striking and significant difference that must be borne in mind. The tourmalines and chondrodites so abundant in and characteristic of the North American limestone, appear to be nearly, if not altogether, absent from the Mogok limestone.

At St. Gothard, corundum is also found embedded in a dolomitic limestone, and here, too, it is associated with tourmaline.

The researches of LAWRENCE SMITH† and TSCHERMAK‡ have shown that the emery

* J. F. KEMP, "The Ore Deposits at Franklin Furnace and Ogdensburg, N.J." ('Trans. N.Y. Acad. Sci.,' vol. 13 (1893), pp. 76–98).

† 'Am. J. Sc.,' vol. 7 (1849), p. 283; *ibid.*, vol. 10 (1850), p. 354; and vol. 10 (1851), p. 53.

‡ 'Min. u. Pet. Mitth.,' Bd. 14 (1894), p. 311.

variety of corundum of Asia Minor also occurs in limestone. The last-mentioned author has proved that the following minerals enter into the constitution of the emery itself—corundum, magnetite, tourmaline, chloritoid, muscovite, margarite, and calcite—the last three being probably products of the alteration of the corundum itself. The list of minerals found in the corundum-bearing limestone, according to these two authors, includes diaspore, gibbsite, (hydrargillite), spinels (including gahnite or zinc spinel), muscovite, phlogopite, biotite, vesuvian, margarite, chloritoid, and other clintonites, rutile, ilmenite, magnetite, hematite, staurolite, kyanite, pholerite, kaolinite, and tourmaline.

With respect to the origin of the remarkable limestone in which the Burmese gems occur, I have been unable to find the slightest evidence that it has been formed by the alteration and recrystallization of an organic deposit; on the contrary, all the facts point to a totally different conclusion.

The limestones of Burma are, as we have seen, most closely associated and intimately interfoliated with granitic and gneissic rocks, and especially with the unstable pyroxene and scapolite-bearing gneisses. Between these pyroxene-gneisses and the limestone we find every intermediate type of rock. Gneisses in which calcite is an important constituent (see fig. 17, p. 203) pass quite insensibly into rocks in which the same varieties of pyroxenes, amphiboles, and mica occur, but in which, by the increase of calcite, the rock becomes a true "calciphyre," like that of Tiree.

Now all modern researches point to the conclusion that the pyroxene- and other gneisses resembling those of Burma were of igneous origin, and the limestones have certainly not the appearance of having become associated with the gneisses by the intrusion of the latter among them. On the contrary, when we come to study the metamorphism of the minerals in these gneisses, calcite is found to be constantly one of the final products of the changes which have gone on in the rocks. The abundant lime-soda felspars (labradorites) of the pyroxene-gneisses have been everywhere converted into scapolites (dipyre, &c.), the change having being brought about (as in the case of the analogous rock of Bamle, which I have investigated) by the action of hydrochloric acid under pressure. For this change LACROIX has proposed to use the term "Werneritization." But the scapolite is itself a very unstable mineral, and calcite is the constant product of its decomposition. It appears to me probable, therefore, that the calcite so frequent in these highly crystalline rocks, whether occurring as disseminated crystals through the gneiss or as great interfoliated masses, is really neither altered organic limestones nor of ordinary chemical (tufaceous) origin, but have resulted from the metamorphism of the lime-bearing felspars.

[If this be the case, it is, of course, necessary to suppose that the calcium carbonate has been often transported to new localities in solution, while the basic aluminium and other silicates have in some cases been broken up, so as to give rise to the formation of corundum, spinel, and the various other minerals occurring in the limestone or in the rocks so closely associated with it.—October 7th, 1895.]

If this view of the origin of the gem-bearing limestones be accepted, we may possibly find means of accounting for the formation of the gems, corundum, and spinel themselves.

It may be remarked at the outset of our enquiry that the association of corundum and spinel, with such varied minerals in different cases, points to the conclusion that these gems have not always owed their origin to the same set of causes.

In the great belt of corundiferous rocks in the eastern part of the United States, corundum has been shown to be constantly associated with ultra-basic rocks (peridotites), more or less completely converted into serpentine, and included in a series of highly metamorphic masses.

But corundum is no less frequently found in association with more acid rocks. Near Mozzo, in Piedmont, corundum occurs in a felspar-rock, in the Riesengebirge in granite, and in the Zanskir mountains of Cashmere and many other localities in gneissic rocks.

At Pipra, in S. Rewah, and at other points in Central India, masses of corundum-rock of enormous thickness and extent have been found interfoliated with the crystalline gneisses and schists.*

Corundums are found, probably produced by contact metamorphism, in basaltic lavas (Unkel-on-Rhine, and especially near Le Puy, &c.), and in blocks ejected from volcanoes (Laacher See, Niedermendig, Königswinter, &c.).

In limestones, corundum occurs usually in association with tourmaline and chondrodite, as at Orange Co., N.Y., and Sussex Co., Jersey, St. Gothard, Naxos, and other localities; and at other times, as in Burma, in limestones without the minerals containing boric acid and fluorine.

There are two other modes of occurrence of corundum which are of especial interest. HENRI STE.-CLAIRE DEVILLE showed† that when the natural hydrated aluminium oxide of Baux (bauxite) is fused with caustic soda, digested with water, and then treated with nitric acid, a few grains of considerable hardness are left behind. These hard grains resist the action of acids, but dissolve in fused potassium bisulphate. On analysis they were found to be aluminium oxide containing traces only of iron, titanium, and vanadium. The hard grains were by these tests proved to be corundum.

M. MOISSAN has shown that the remarkable iron-masses of Ovifak, Disco Island, Greenland, contain disseminated grains of corundum sapphire.‡

Spinel probably occurs in all, or nearly all, the different associations in which we find corundum, and, indeed, the association of the two minerals with one another is of frequent occurrence.

* See 'Mining Mag.,' vol. 11 (1895), p. 57; and 'Records of Geol. Survey of India,' vol. 5, p. 20, and vol. 6, p. 43.

† 'Ann. de Chim. et de Phys.,' vol. 61, p. 309; 'Chemical News,' vol. 4 (1861), p. 341.

‡ 'Compt. Rend.,' 116, p. 269.

If we now turn our attention to the processes which have been devised for causing aluminium oxide to assume the crystallized form, and thus produce corundum, we shall find that no less than twenty methods are now known by which this end may be attained. They are as follows :—

1. Fusing aluminium oxide in oxyhydrogen flame (GAUDIN, 1869).
2. Heating alum alone or with potassium sulphate (GAUDIN, 1839).
3. Heating aluminium chloride in closed tube (suggested by GAY LUSSAC, accomplished by MEUNIER, 1880).
4. Heating aluminium oxide with borax (EBELMEN, 1851).
5. Heating aluminium fluoride with boric acid (DEVILLE and CARON, 1857).
6. Acting on aluminium oxide, at a red heat, with hydrofluoric acid (HAUTEFEUILLE, 1865).
7. Heating sodium aluminate with hydrochloric acid (DEBRAY, 1865).
8. Heating aluminium phosphate with potassium sulphate (DEBRAY, 1865).
9. Heating aluminium oxide with minium in a crucible (FRÉMY and FEIL, 1877).
10. Heating aluminium oxide with a fluoride in the presence of an alkali (FRÉMY and VERNEUIL, 1887).
11. Melting together microcline and fluorspar (FOUQUÉ and M. LEVY, 1884).
12. Heating to redness for one hour cryolite and a silicate (LACROIX, 1887).
13. Heating aluminium oxide with silica and cryolite (MEUNIER, 1880).
14. Melting nepheline (P. HAUTEFEUILLE and A. PERREY, 1890).
15. Acting on aluminium oxide by water at a red heat (MEUNIER, 1880).
16. Heating aluminium oxide with soda to 530° to 535° C. for 20 hours (FRIEDEL, 1891).
17. Heating solution of aluminium chloride to 350° C. in closed vessel (SENARMONT, 1850).
18. Heating solution of aluminium nitrate to 350° C. in closed vessel (SENARMONT, 1850).
19. Heating aluminium oxide with water and trace of ammonium fluoride to 300° C. for 10 hours (BRUHNS, 1889).
20. Heating solution of aluminium sulphate in closed tube to 160° to 180° C. (WEINSCHENK, 1890).

It would be rash to suggest that any one of the methods enumerated above was the one by which corundum has been naturally produced in any particular rock. But it is evident that by these, or similar, reactions, crystallized aluminium oxide may have been formed in deep-seated rocks, under enormous pressure, at even moderate temperatures, and that, with sufficient time, the crystals may have grown to considerable dimensions.

The general conclusions concerning the origin of the rubies of Burma, to which we have been led by these studies then are as follows : Pyroxene-gneisses abound, with an unstable basic felspar (labradorite or anorthite), which is easily converted by the action of minute quantities of hydrochloric acid under pressure into a scapolite ; the scapolite in turn breaking up into various hydrated aluminium silicates and calcite. In some cases, however, the basic silicate may be converted directly, by carbonic or other acids, into a mass of hydrated silicates, quartz, and calcite. Examples of such a change are found in the cavities of many amygdaloidal basic rocks. LIEBRICH has recently shown that among the products of decomposition in a basalt of Rudigheim, near Hanau, is a special form of calcium carbonate occurring in nodular concretions with spheroidal and concentric structure, in masses up to and more than a foot in diameter. It is noteworthy that this limestone is associated with clay, *bauxite*, and hyalite.* A similar case, occurring in South Africa, has been communicated to me by Mr. D. DRAPER, F.G.S. In this connection, it must be remembered how frequently calcareous materials make their appearance in masses of altered basic rocks—the "kalk-diabases," "kalk-aphanites," &c., of many authors. The rocks known to French geologists as "hemithrènes," are probably of similar origin.

While the limestones are being formed from basic felspars, the aluminium silicates taking up water may also be attacked by sulphuric, hydrochloric, boric, or hydrofluoric acid acting at moderate temperatures, and the salts of aluminium thus formed are easily decomposed ; the aluminium oxide, either hydrated (diaspore, gibbsite, bauxite, &c.) being set free, or under certain conditions of temperature and pressure the anhydrous oxide itself being formed. The slowly liberated oxide may assume the crystalline form, and thus give rise to corundum. That the crystallization of the aluminium oxide took place under great pressure, and probably at moderate temperatures, is indicated by the circumstance that the crystals include not only cavities containing supersaturated solutions of chlorides, sulphates, &c., but also, in some cases, liquid carbon dioxide, which remains liquid at all ordinary temperatures, below the critical temperature for that gas.

3. *Metamorphoses of the Rubies and Associated Minerals of Burma.*

At the earth's surface, as is well known, corundum, or the crystallized oxide of aluminium, is one of the most unalterable of substances. Fragments found in river gravels and sands, though perfectly water-worn, show no trace of chemical alteration in their surfaces. On the other hand, there can be no doubt that conditions must exist in the earth's crust, under which chemical change of this mineral does take place ; this is abundantly proved by the frequency with which undoubted

* 'Neues Jahrb.,' 1893, vol. 2, p. 75.

pseudomorphs of corundum occur. Among the minerals found replacing corundum as pseudomorphs are muscovite (damourite), various forms of spinel, andalusite, fibrolite, cyanite, margarite, chloritoid, zoisite, ripidolite, and other chlorites, various vermiculites, kaolin, and other substances. The hydrates of alumina, diaspore and gibbsite, are seldom, if ever, found as pseudomorphs after corundum because (as is so well seen in the case of the diaspore of Dilln, near Schemnitz) the hydrated oxides of aluminium very readily enter into combination with silica, forming various silicates. The spinels, so commonly associated with corundum, are also frequently altered; pseudomorphs after spinel in hydrotalcite, serpentine, talc, and hydrous biotites being well known to mineralogists.

Between the years 1849 and 1851, the late Professor J. LAWRENCE SMITH, published several important memoirs on corundum and emery.* One very striking fact established by the experiments and analyses of this able observer, was that all forms of corundum and emery (excluding the fine gem-varieties known as ruby, sapphire, &c.) contain water up to about 3 per cent., with varying proportions of silica, lime and iron oxide. LAWRENCE SMITH also showed that the abrasive power of corundum steadily diminishes as the proportion of water present in it increases; and he was clearly of the opinion that the water in these specimens of corundum is combined with a portion of the alumina forming a hydrate disseminated through the mass. In connection with this subject he remarks: "Of all the specimens that I have collected, none offer so much interest as those composed of diaspore embedded in corundum; here we see the two minerals passing one into the other, without being able, in many places, to distinguish the line of separation, so imperceptible is the gradation. After what has been said in respect to corundum, it is not astonishing to see the connection of alumina, more or less hydrated, with a hydrate of alumina of definite composition."†

To another distinguished American mineralogist, the late Dr. F. A. GENTH, we are also indebted for many valuable observations which illustrate the ease with which corundum becomes hydrated, and then, by combination with silica, is converted into a great variety of crystallized minerals. In his valuable memoir on "Corundum, its Alterations and Associated Minerals," published in 1873, Dr. GENTH showed by a series of careful analyses, how remarkable have been the series of metamorphoses which this mineral has undergone, in the great corundiferous belt of the Eastern United States.‡ RAMMELSBERG, it is true, in the second edition of his 'Handbuch der Mineralchemie,' published in 1873, threw some doubts on the results announced by GENTH; § but in a later memoir, published in 1882, the latter author fully established

* 'Am. Journ. Sci.,' series 2, vol. 7, (1849), p. 283. *Ibid.*, vol. 9 (1850), pp. 289, 354. *Ibid.*, vol. 11 (1851), p. 53.

† *Ibid.*, p. 58.

‡ 'Proc. Am. Phil. Soc.,' vol. 13 (1873), pp. 361–406.

§ 'Handbuch der Mineralchemie,' 2nd edition, Spec. Theil, p. 147.

the accuracy of his conclusions.* As the result of his studies, GENTH wrote, "May it not be that the diaspore is so very finely distributed through the corundum, that even the best microscopic or other examination could not detect it, as I have just shown with regard to the admixture of corundum and spinel."†

In many cases, alteration of corundum into diaspore can be seen, in thin sections under the microscope, to have taken place along the planes of secondary parting following the rhombohedron. The reduction in specific gravity of the mineral serves as a measure of the hydration that has taken place. Thus, in an altered corundum from the United States, I found the specific gravity to be 3·88, while in a still more altered specimen from Rekwanna, Ceylon, given to me by Mr. C. BARRINGTON BROWN, the density was as low as 3·79. As the density of unaltered corundum is 4·02, and of diaspore is 3·32, we may calculate that the American specimen consists of four parts of corundum united with one part of diaspore; while the Ceylon specimen is made up of two parts of corundum with one of diaspore. In the last-mentioned specimens the presence of diaspore can be detected by the naked eye. The corundum crystals break easily along the rhombohedral parting-planes; and these are seen to be covered with films of diaspore, exhibiting its characteristic colour and lustre. Common corundum has an average specific gravity of 3·93, and may, therefore, be regarded as a combination of six parts of corundum with one part of diaspore. It must be remembered, however, that in many cases the change has proceeded one step farther, and various silicates have been formed from the hydrated alumina.

The hydration of corundum, and the union of the diaspore thus produced with silica and certain bases to form various silicates, is admirably illustrated in the case of the Burma examples. Scattered through the highly crystalline limestone we find a number of rubies, most of these being enveloped by a mass which clearly consists of the products of alteration of the crystallized aluminium oxide. In some cases the rubies are only surrounded by a thin shell of these alteration products, but in other instances every trace of the original ruby has disappeared, and the products of its decomposition fill the space once occupied by it. Under the microscope thin sections enable us to follow out the several stages of the metamorphism that has taken place. Immediately around the unaltered ruby there is always a layer, varying in thickness, of pure diaspore (hydrated alumina); but as we pass outwards we find this replaced by mixtures of various hydrated silicates, such as margarite, damourite, kaolin, &c., into which the diaspore insensibly passes (see Plate 6, figs. 10, 11, 12). The latter change is quite similar to that observed in the well-known case of the diaspore of Dilln, near Schemnitz, which has been investigated by A. HUTZELMANN‡ and other authors.

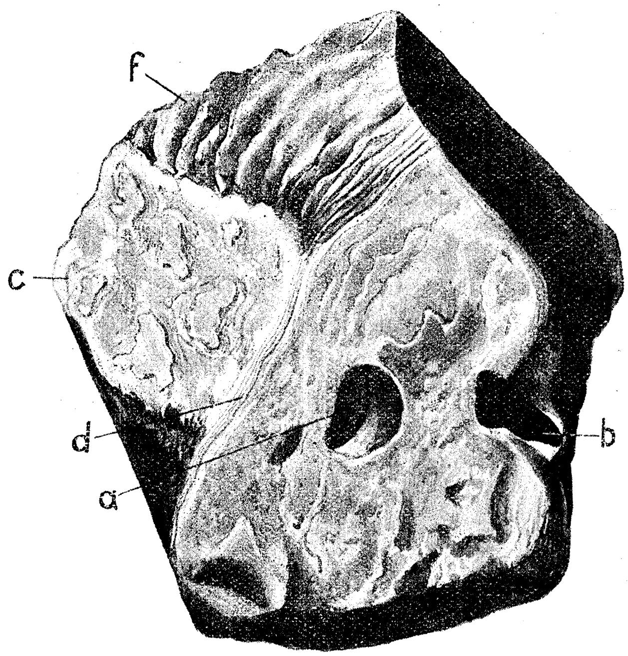
* 'Proc. Am. Phil. Soc.,' vol. 20 (1882–3), pp. 381–392. See also, 'Am. Journ. Sci.,' 3rd series, vol. 39 (1890), pp. 47–50.

† 'Proc. Am. Phil. Soc.,' vol. 13 (1873), p. 372.

‡ 'Bull. Freund. der Naturwiss.,' Wien; 'POGG. Ann.,' vol. 28, p. 575; 'Am. Journ. Sci.,' 2nd ser., vol. 10 (1850), p. 247; also Berg u. Hütten. Zeitschr.,' vol. 10 (1851), 11–12.

In a recent communication to the Mineralogical Society* I have shown that in the corundum, which has not been subjected to pressure and thus had gliding planes developed in it, the fracture is conchoidal like that of quartz. In such untwinned

Fig. 18.



crystals there is a plane of chemical weakness parallel to the basal plane (0R., 100). This is shown by the frequency of a pearly lustre on that face, due to the development of films of diaspore within the crystal, and sometimes also by a tendency of the crystal to break up parallel to this plane. Now the presence of this plane of chemical weakness is very strikingly exhibited by some Burmese rubies.

Fig. 18 represents a much-altered ruby crystal, magnified four diameters. The basal plane has been attacked irregularly, and the deep holes *a* and *b* show how capriciously such erosive action sometimes goes on; at *c* we have a rhombohedral face undergoing the kind of exfoliation, of which we are about to speak as characteristic of those planes of the crystal, but at its upper part, *d*, we see that the crystal is made up near the much-weathered basal plane of alternate layers of corundum and diaspore. The same fact is still better shown on the fractured surface *f*. It is this alternation of diaspore layers which gives the pearly lustre so often exhibited on the basal plane of corundum crystals.

When, in consequence of pressure, gliding planes (similar to those produced in calcite) have been formed in corundum, chemical action tends to take place along these gliding or secondary twinning planes.

In rubies embedded in the limestone, the faces parallel to the rhombohedron are

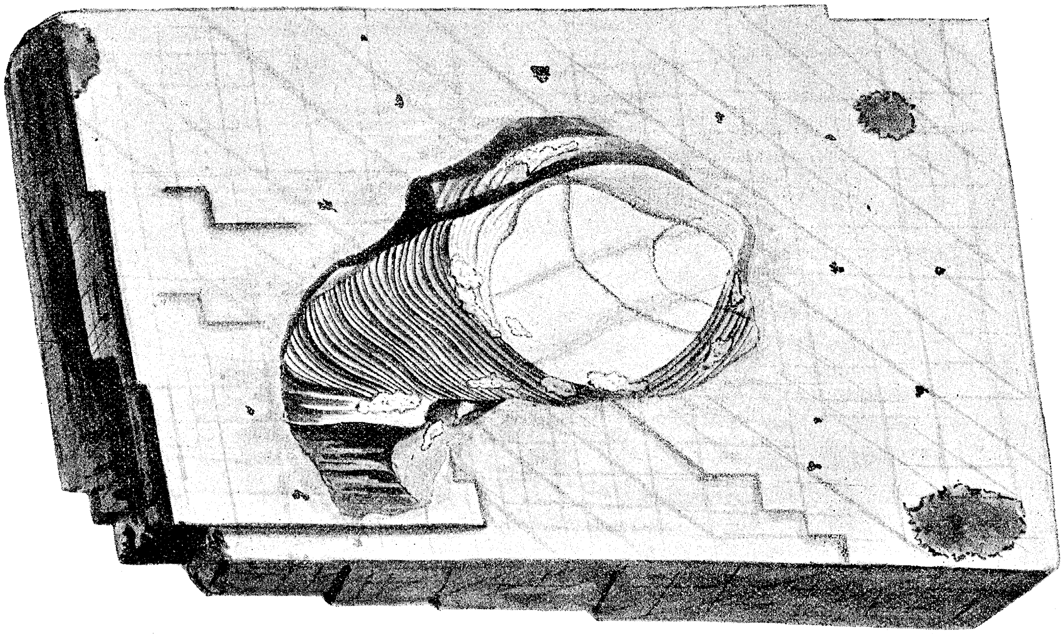
* 'Mineralogical Magazine,' vol. 11 (1895), p. 49.

seen to display a series of step-like ridges like those of a contoured model, or those exhibited by the well-known Babel quartz (see fig. 18, *c.*).* This character is admirably illustrated by the fine ruby (evidently from Burma) which has been presented by Mr. RUSKIN to the British Museum collection, under the name of the "Edwardes Ruby." It is evident that the hydration and conversion of the corundum into diaspore has not gone on with perfect uniformity, but has been controlled by the existence of planes of chemical weakness parallel to the faces of the primitive rhombohedron.

In some cases, however, the eating into the corundum crystal by the formation of the hydrate (diaspore) appears to go on in a very capricious manner indeed; irregular depressions are formed extending quite into the interior of the crystal (see fig. 18, *a* and *b*), and thus it is gradually reduced to a shapeless mass.

The most characteristic of all the methods of breaking up of the Burmese rubies by hydration and chemical action is that exhibited when the rhombohedral faces of the crystals are attacked along the twinning planes that become solution-planes.

Fig. 19.



In the specimen figured above (fig. 19), which is enlarged 5 diameters, a piece of the Mogok limestone, showing both cleavage and twinning planes, is seen having embedded

* [It might, of course, be argued that the peculiar forms of these corundums and spinels are due to irregularities in the growth of the crystals, as in the Babel quartz and certain varieties of fluor and many other minerals. But that, in the case of the corundums and spinels of Burma, the appearances presented are actually due to corrosion seems to be proved by the fact that in so many instances the products of alteration can be seen still surrounding the unaltered gems.—October 7, 1895.]

in it a fine ruby of excellent colour. The rhombohedral faces of the crystal are found to exhibit the characteristic step-like surfaces, and upon these white patches of diaspore can still be seen. This mass of limestone exhibits several pseudomorphs after smaller rubies, and some grains of graphite and pyrrhotite, all enclosed in the calcite.

Fig. 20.

[There is a remarkable analogy between the way in which the rubies of Burma break up along their rhombohedral planes, during hydration, and the disintegration of the diamond during its oxidation (combustion). Mr. J. JOLY, F.R.S., in his account of experiments made to determine the thermal expansion of the diamond ('Nature,' March 22, 1894) writes as follows :—

"At a temperature of 850°, and indeed below this, observations were stopped by the 'efflorescence' upon the surface of the diamond of flaky particles which wriggled and twisted in a peculiar manner, finally disappearing. Once started, the 'combustion' continued till the temperature of the oven was lowered to 712°. Cooling the oven, I subsequently photographed one face of the diamond. The picture obtained shows the face with a lamellar appearance, which was produced entirely by the heating, as at starting the faces were smoothly curved. Such an appearance is occasionally observed upon specimens of diamond. This photograph, as well as the curve of expansion, were shown at the *soirée* of the Royal Society in June, 1892."

I am greatly indebted to Mr. JOLY for copies of this very interesting photograph, and for permission to insert a reproduction of it (fig. 20) in illustration of this paper.] —December 8, 1895.

But there is yet another method of the breaking up of corundum and spinel crystals, which is of the greatest interest to crystallographers and mineralogists.

The hydrates and silicates have in some cases been produced along more or less irregular depressions, but these have shown such a general tendency to follow definite directions within the crystal that the result has been a mass built up of granules, each having an approximately crystalline form. Fig. 21 shows a crystal of black spinel (ceylanite), the summit magnified 2 diameters, the faces of which show etched figures, but at one angle this etching has gone so far as to leave a number of octahedral figures standing out in relief. In fig. 22 (also magnified 2 diameters) of a purple spinel from Burma the whole crystal is found broken up in the same manner, into an aggregate of small rhombohedral polysynthetic crystal of some authors. These resultant masses resemble in a striking way the models built up of "fundamental forms" by which HAÜY and other crystallographers have sought to illustrate their ideas of crystals architecture. In the case of the spinel, the form of the granules into which the large crystals break up, is the regular octahedron. A very large and remarkable specimen of spinel from Burma, in the possession of Mr. STREETER, exhibits this peculiarity in the same striking manner as the smaller ones figured. Beginning with natural etched figures (Verwitterungsfiguren), we find in these cases that the depressions become deeper and deeper till the whole crystal is reduced to a skeleton-like mass.

[A very interesting problem which suggests itself to the student of these remarkable changes in the corundum and spinel, is that of the time and place at which they must have taken place. That, at ordinary temperatures and pressures, both

Fig. 21.

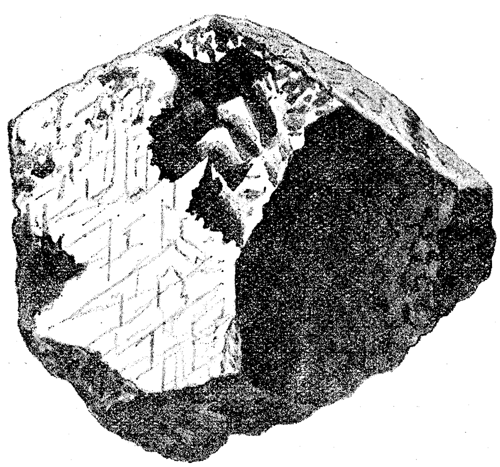
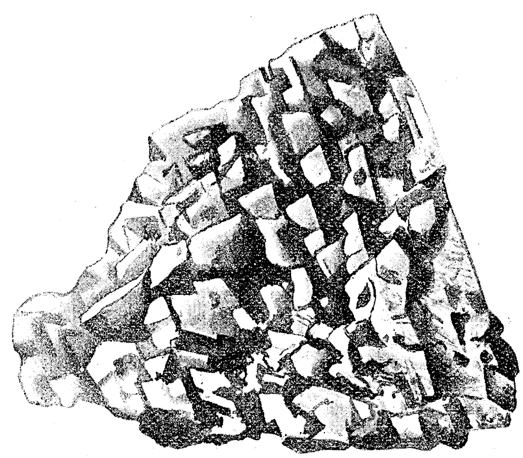


Fig. 22.



corundum and spinel are very slowly, if at all, acted upon by atmospheric agencies, is shown by the condition of the specimens found in alluvial deposits. In spite of the extreme hardness of the gems, they may be found to have suffered greatly from mechanical attrition while exhibiting little if any evidence of chemical change. The hydration of the oxides and their union with silica must have been brought about, therefore, while they still constituted portions of deep-seated masses, and were acted upon by solvents under pressure. The very interesting specimens from Sagyin, recently sent me by Mr. HOLLAND, seem to prove that, in certain cases, the corrosion of the spinel crystals must have taken place *before* their enclosure in the limestone. The fine spinels, nearly an inch in diameter, are found with their surfaces showing the incipient alteration to which I have referred. In these cases, it would seem that the growth of the spinel crystals and their partial alteration by solvent action going on irregularly over their surfaces, must both have been accomplished before the deposition of the calcite in which they are now found to be completely embedded. In the case of the Mogok limestones, however, the fact that the unaltered rubies are seen lying in the midst of a mass of their alteration products, the whole being enclosed in the limestone, seems to prove conclusively that the changes took place *after* the formation of the latter rock.—October 7, 1895].

VIII.—SUMMARY OF RESULTS.

The chief scientific results to which we have been conducted by these studies, are as follows :—

1. The famous rubies and spinels of Burma have now been found *in situ* in a highly crystalline limestone, containing various silicates and oxides, with pyrrhotite (magnetic pyrites) and graphite.

2. The equally famous rubellite (red tourmaline), so highly prized by the Chinese, though found in the same district, does not occur in actual association with the corundum and spinel in the limestones, but is found in certain acid rocks (aplites) associated with the gneisses and schists.

3. The limestone containing rubies and spinels is very intimately associated with certain highly basic foliated rocks :—pyroxene - gneisses and granulites, with pyroxenites and amphibolites.

4. Unlike most crystalline limestones which have yielded corundum and spinel, the Mogok rock does not appear to contain silicates combined with fluorine and boron.

5. The source of the crystallized aluminium oxide (corundum), the aluminate of magnesium (spinel), and the calcite in which these minerals are embedded, appears to be the basic lime-felspar (anorthite) and associated minerals of the pyroxene-gneisses. The anorthite is often converted into scapolite, from which calcite and various hydrated aluminous silicates have been formed by further alteration.

6. The hydrous aluminous silicates have been shown, under certain conditions, to break up and give rise to silica (opal) and hydrated aluminium oxide (diaspore, gibbsite, bauxite, &c.).

7. The hydrated aluminium oxide, under other conditions of temperature and pressure, becomes dehydrated and may crystallize as corundum.

8. While the crystallized aluminium oxide at the earth's surface is one of the

most unalterable of substances, this is not the case with the mineral as it exists at considerable depths in the earth's crust.

9. The anhydrous oxide easily takes up water and recrystallizes as diaspore, and many examples of corundum, as suggested by LAWRENCE SMITH and GENTH, really consist of intimate admixtures of the anhydrous and hydrous oxides of aluminium.

10. Unaltered corundum is, like quartz, a mineral without any true cleavage and breaks with a conchoidal fracture.

11. The common partings parallel to the primitive rhombohedron which are so often found in corundum, are gliding planes produced by pressure.

12. In addition to these partings, produced by mechanical means, there are others which are developed by chemical means, namely, hydration and union with silica and other oxides. This action tends to take place along definite crystalline planes—solution planes—which are parallel to the base and hexagonal prism.

13. If, however, the crystal has been subjected to pressure, and had the rhombohedral gliding planes developed in it, such planes become secondary-solution planes, along which chemical changes proceed very rapidly.

14. By the formation of diaspore and the union of diaspore with silica and other oxides, the corundum gradually diminishes in hardness, lustre, and density; the changes sometimes appearing to go on in a perfectly capricious manner from the surface of the crystal, but more usually following either the primary solution planes, or, if the crystals have been subjected to mechanical change, the secondary solution planes. This change took place in some cases before, and in others after, the minerals were embedded in the limestone.

15. The final result of these processes is to convert the corundum crystal into one of those pseudomorphs in hydrated silicates, damourite, margarite, chlorites, vermiculites, &c., which are so familiar to all mineralogists.

EXPLANATION OF PLATE 6.

NOTE.—In describing the actual dimensions of the objects represented on this plate, the magnifying power of the objective is given as the numerator, and the reduction for the purposes of drawing as the denominator. The quotient, therefore, gives the actual linear enlargement.

Fig. 1. Fine-grained pyroxene-gneiss, resembling a gabbro in its characters. It consists of plagioclase felspar, with a little quartz and orthoclase, the latter showing much of the "quartz of corrosion" of French authors. The crystals thus attacked are indicated by faint shading. The pyroxenes, which are present in moderate quantities, belong to both augite and

enstatite; the former showing the two sets of secondary parting planes, characteristic of "pseudo-hypersthene," the latter being highly ferriferous and strongly pleochroic (hypersthene). The rock was obtained from Hmyaudwin, No. 13, Mogok. $\times \frac{10}{3}$.

Fig. 2. Pyroxene-granulite, with scapolite and calcite. This rock consists largely of an untwinned felspar in rounded grains, among which are many grains of scapolite and a considerable number of grains of calcite. The rock is very distinctly foliated, and streams of liquid cavities can be traced passing continuously through contiguous grains. The ferro-magnesian silicate is a purplish, non-pleochroic augite, probably titaniferous. The rock was obtained, *in situ*, at Letnytoung mountain. $\times \frac{25}{3}$.

Fig. 3. Sahlite-scapolite granulite. In this rock the whole of the felspar appears to be converted into scapolite, with some calcite. The pyroxene is a white augite (sahlite) which, on the outer margin of its granules, sometimes shows tendency towards an alteration to a brown pleochroic material (biotite). Granules of sphene are by no means rare. The rock was collected, *in situ*, at Toungnee mountain. $\times \frac{25}{3}$.

Fig. 4. Sahlite-hypersthene-biotite-granulite. This rock contains not only a monoclinic pyroxene, like the last, but also a considerable amount of a highly coloured and pleochroic rhombic pyroxene (hypersthene), as well as a number of grains of biotite and magnetite, or titanoferrite. There is much quartz, a little plagioclase felspar, and possible orthoclase also. The rock was collected, *in situ*, on the road leading across the pass between Mogok and Momeit. $\times \frac{25}{3}$.

Fig. 5. Pyroxene-biotite-hornblende-hypersthene-granulite with scapolite. This rock differs from the last in having a brown hornblende in addition to the colourless pyroxene, in the relative abundance of the several constituents, and in the large amount of plagioclastic felspar in places largely converted into scapolite. The quartz is present in much smaller quantities A part, at least, of the colourless pyroxenic constituent appears to be wollastonite. This rock was collected in *a* Loodwin, Kathay.

Fig. 6. Hornblende-sahlite-granulite. The pyroxene in this rock sometimes shows the first trace of a paramorphic change into hornblende by very faint pleochroism. The plagioclase felspar is almost entirely unaltered, and there is little or no quartz or calcite in the rock. The rock was collected in No. 9, Hmyaudwin, Mogok. $\times \frac{25}{3}$. (N.B.—The part of the slide figured shows but little sahlite, this mineral being somewhat locally distributed.)

Fig. 7. Pyroxenite associated with the limestones of Burma. This rock consists almost wholly of a green pyroxene with a little quartz and plagioclase felspar and some sphene. In other cases, however, the pyroxene is

largely replaced by a green or brown hornblende, the latter resembling basaltine in its scheme of pleochroism. At the upper part is seen an interesting intergrowth of pyroxene with plagioclase felspar and quartz resembling the "centric structure" of BECKE. $\times \frac{10}{3}$. (These pyroxenites and amphibolites alternate with limestones, and frequently graduate insensibly into the calciphyres.)

Fig. 8. Tourmaline-felspar-quartz rock of Nyoungouk, which yields the rubellite of Burma, the tourmaline which is often beautifully zoned, is an indicolite. The felspar is plagioclastic and sometimes partially changed to scapolite, and the quartz is small in quantity.

Fig. 9. Lapis-lazuli rock—consisting of white diopside, scapolite, and two blue constituents, one deeply tinted, the other pale-tinted (haüyn and lazurite (?)), both perfectly isotropic. In different examples of this rock, the proportions of the white and blue minerals to one another vary greatly. The rock was not found *in situ*, but in blocks of considerable size in ruby workings at Thabanpin. $\times \frac{25}{3}$.

The last three figures illustrate the general nature of the Mogok limestone, and of the alterations which take place in the spinels and rubies enclosed in it.

Fig. 10. Section of limestone from ruby-cave, Mogok—a crystal of corundum is seen lying in this limestone, partially converted into diaspore and various secondary silicates. A bent crystal of the beautiful green chrome-mica (fuchsite) appears in the lower part of the mass and a granule of pyrrhotite at the right. $\times \frac{40}{3}$.

Fig. 11. Spinel and ruby in the midst of the limestone. Ruby-cave, Mogok, 11*a*, shows a crystal of spinel much eaten into and undergoing peripheral alteration, shown by change of colour. Masses of secondary silicates, pseudomorphous after spinel, and scales of graphite are also seen. $\times \frac{25}{3}$. 11*b*, from another part of the same slide, shows two granules of corundum (ruby) broken up and enveloped in diaspore, the whole being surrounded by a zone of mixed silicates. These are evidently examples of ruby undergoing change in the midst of the limestone rock. $\times \frac{75}{3}$.

Fig. 12. Large ruby in the midst of the limestone of Mogok, partially changed into various silicates. Smaller crystals, two intact, and two partially altered, are seen near it. $\times \frac{10}{3}$.

J. W. J.

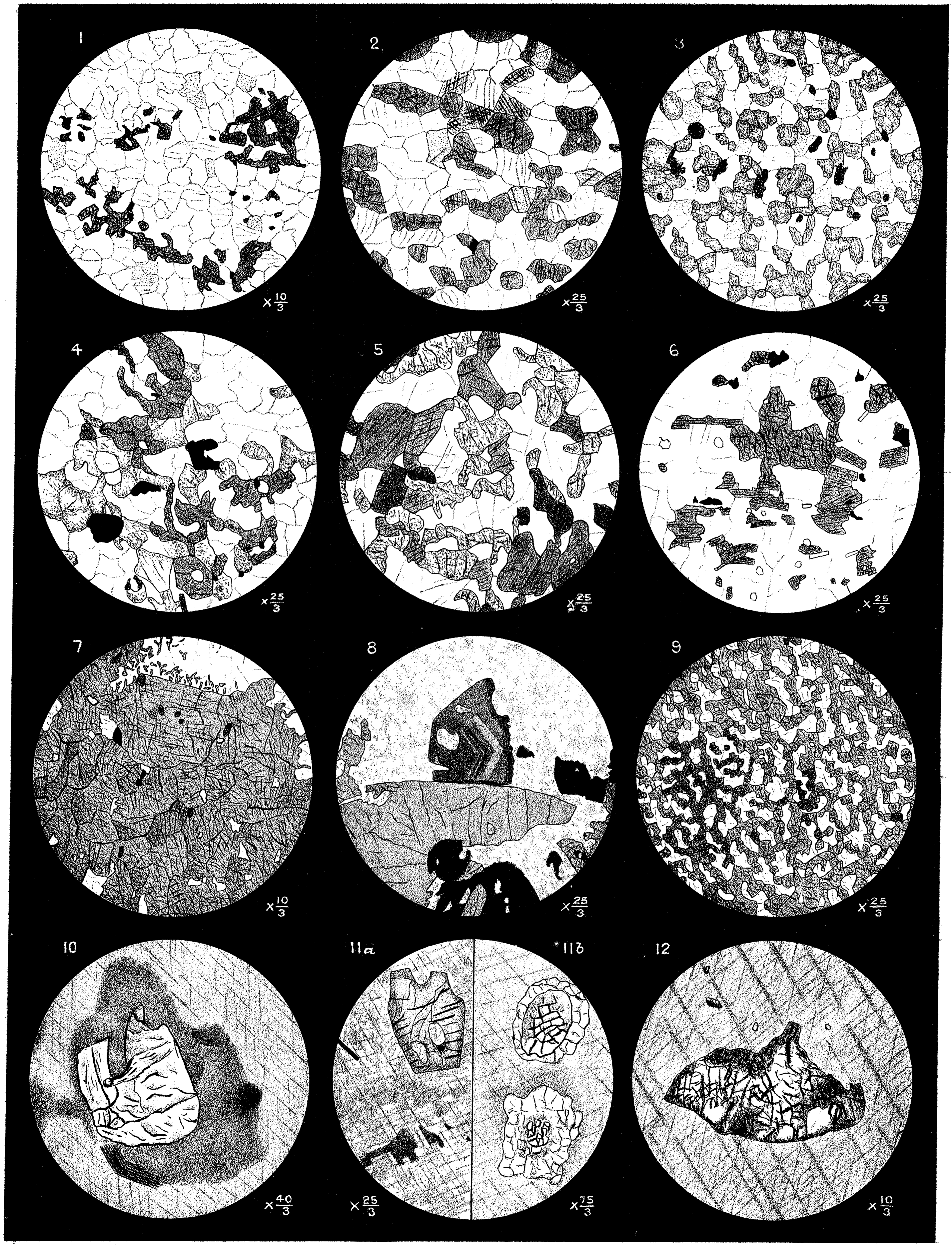
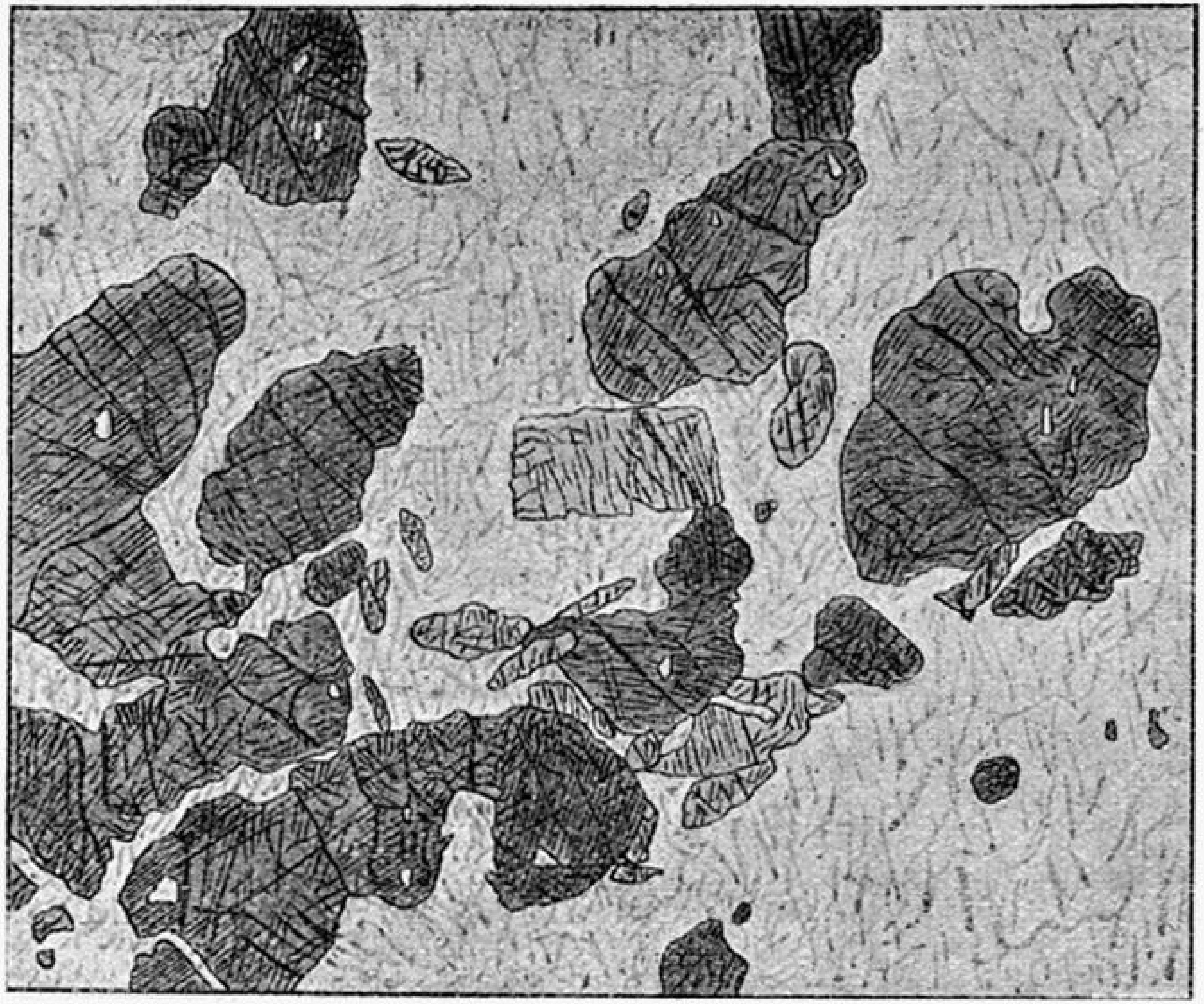

1
×10/3
2
×25/3
3
×25/3
4
×25/3
5
×25/3
6
×25/3
7
×10/3
8
×25/3
9
×25/3
10
×40/3
11a
×25/3
11b
×75/3
12
×10/3

Fig. 15.

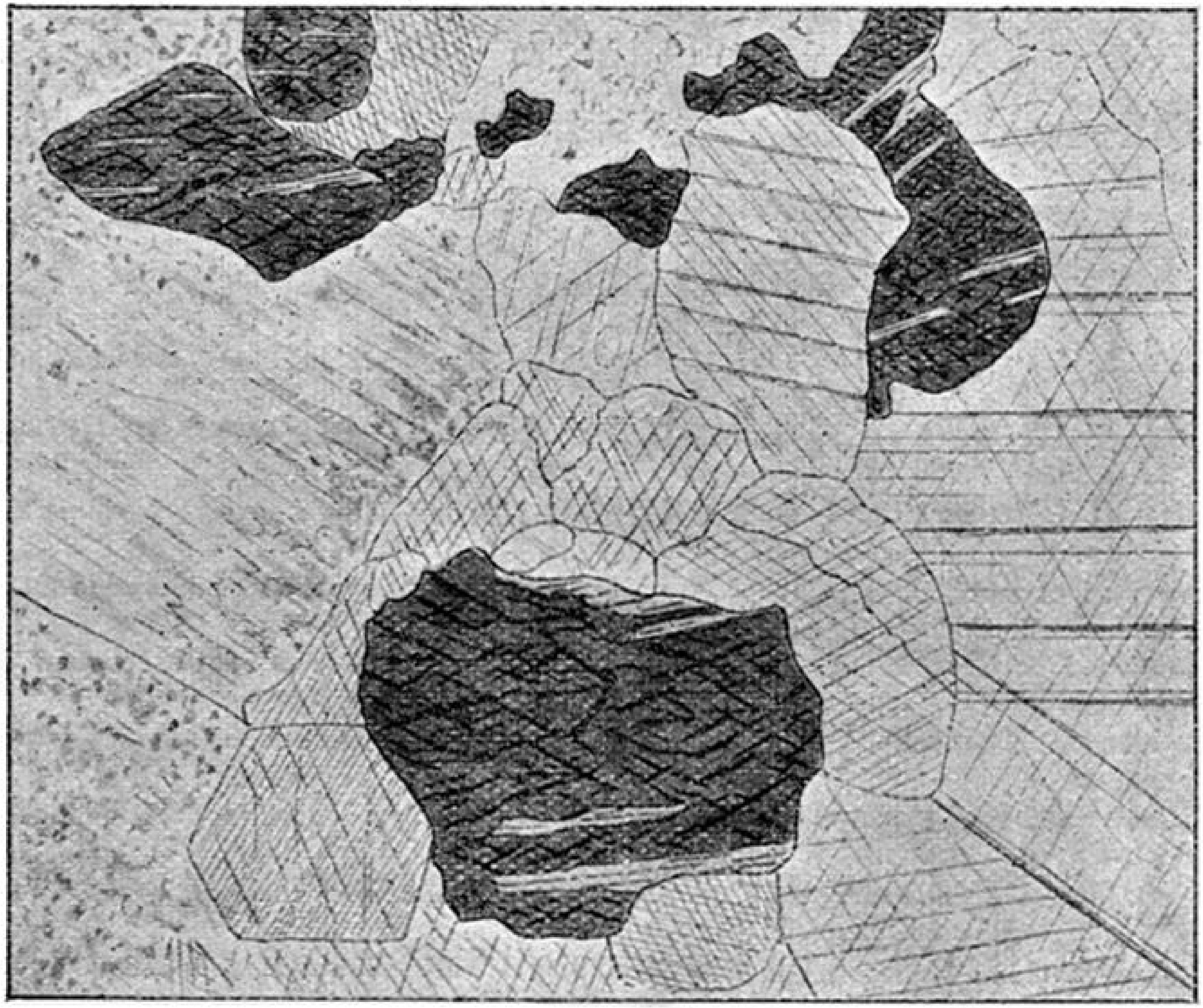


Pyroxene-gneiss, from Mogok. × 3 diameters. The dark crystals are a pale-green augite. The paler crystals a yellowish-brown sphene, and the rest of the slide is made up of a basic felspar near anorthite, which, in this instance, has undergone but little change.

Fig. 16.

Pyroxene-scapolite-gneiss from Mogok. × 3 diameters. Very dark-green pleochroic crystals of augite, are seen scattered through a mass of felspar and scapolite crystals, the latter being so full of inclusions as to show an opalescence like that of "moonstone." In ordinary light the scapolite is distinguished from the felspar by its slightly darker tint.

Fig. 17.



Hornblende-biotite gneiss passing into a caciphyre, from the ridge near Letnytaung × 6 diameters. The dark crystals are deep brown hornblende, with intergrowths of biotite. On the left we have somewhat decomposed plagioclase felspar, while over the rest of the slide calcite prevails.

Fig. 18.

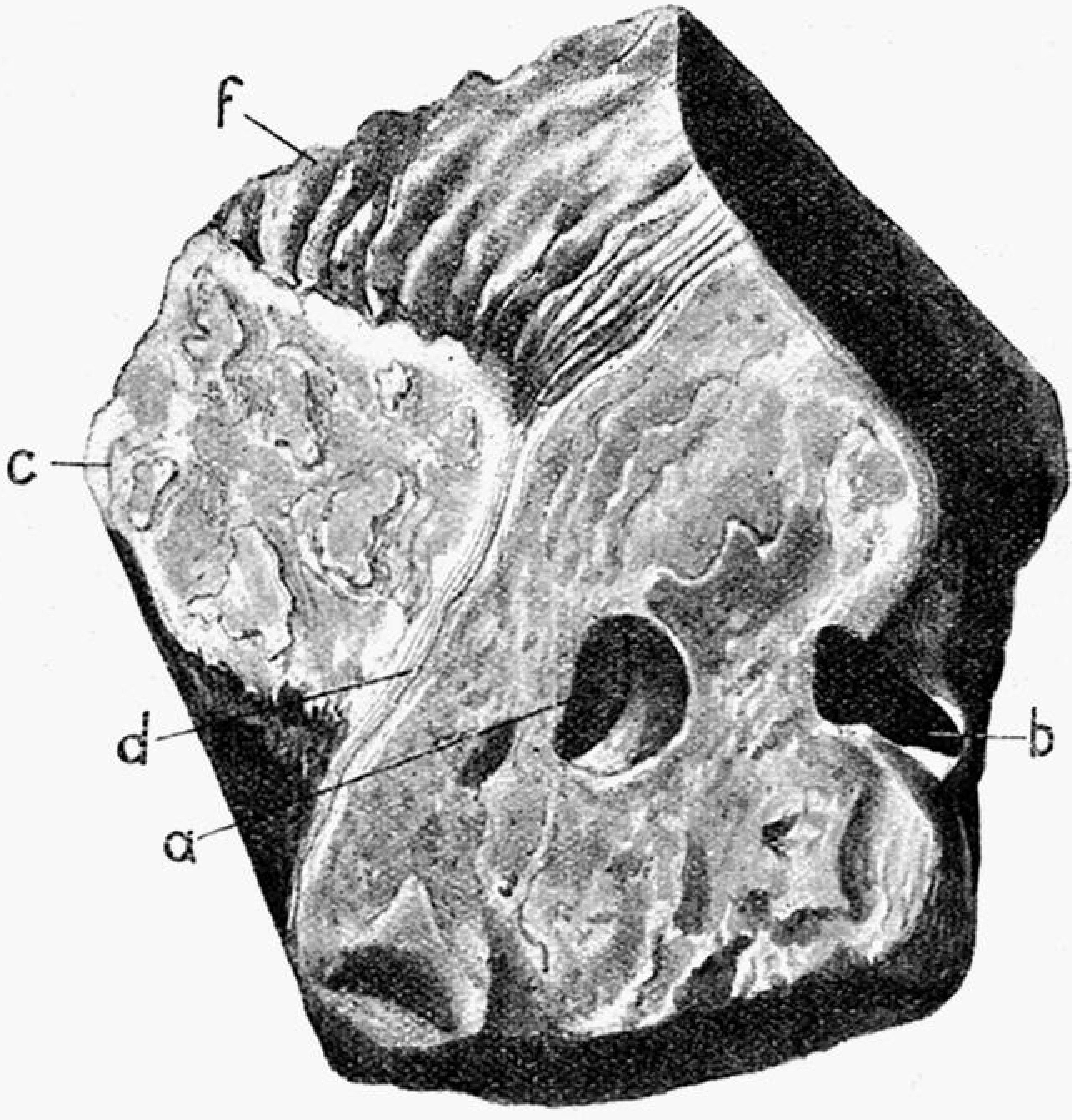


Fig. 19.

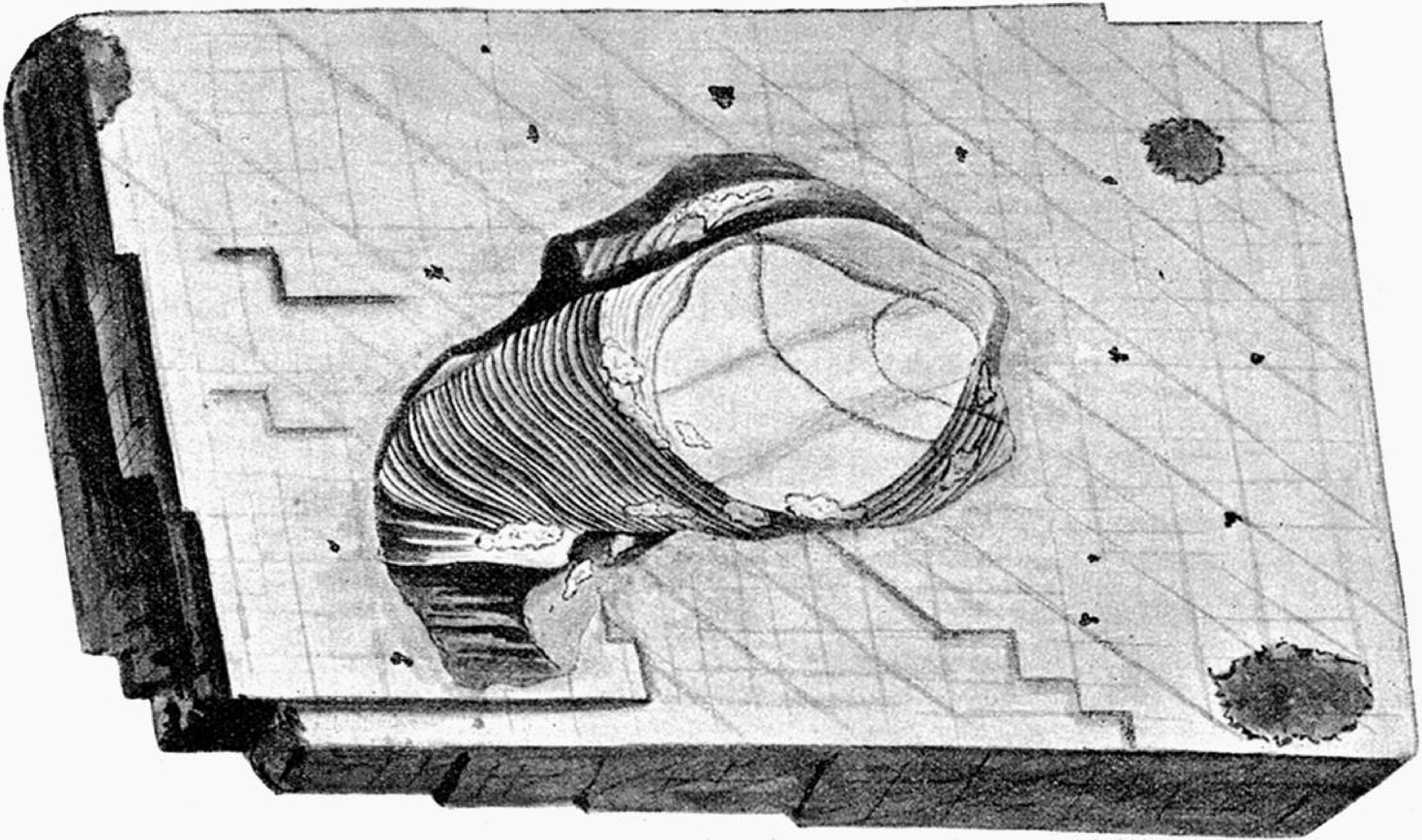


Fig. 20.

Fig. 21.

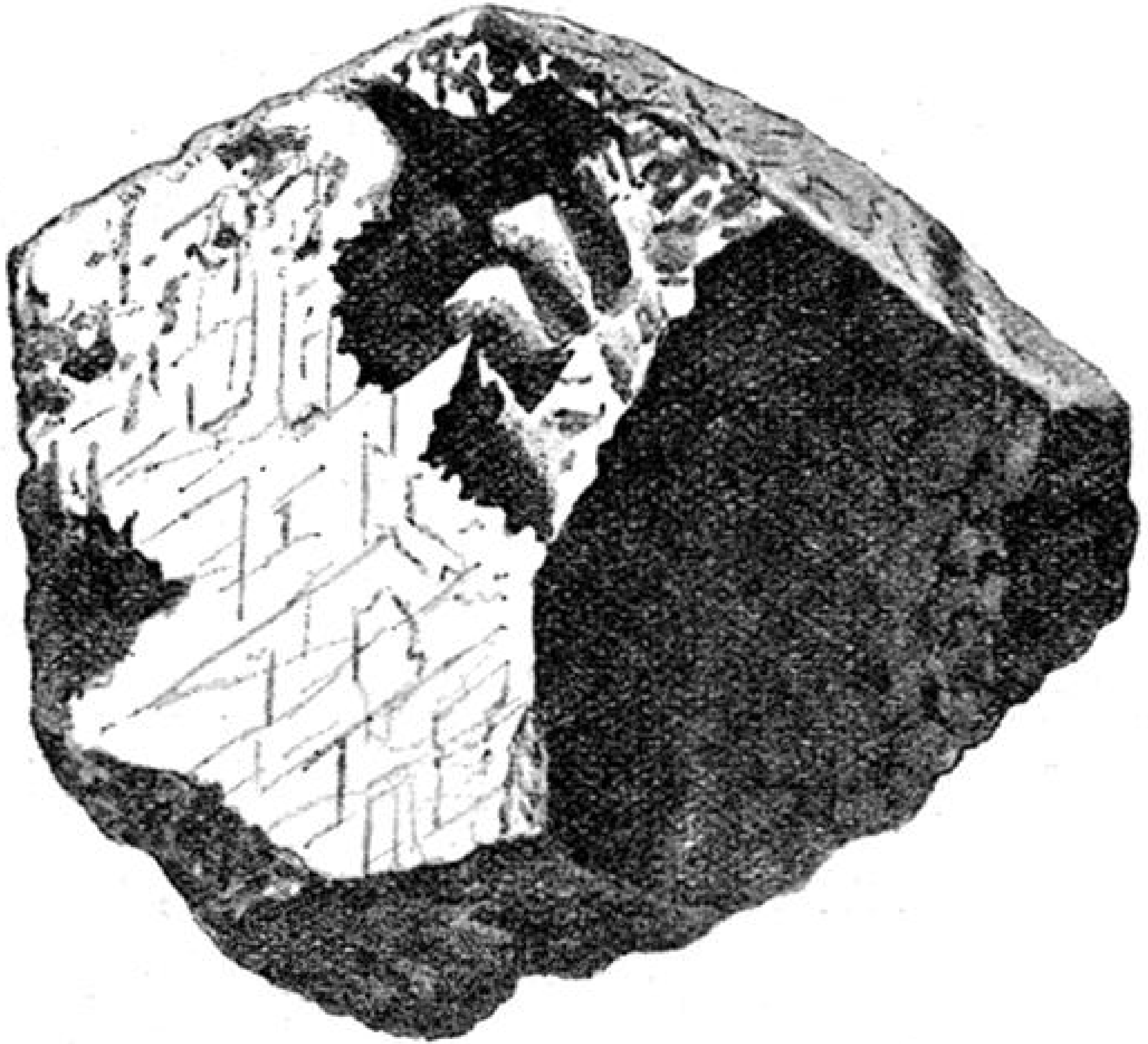
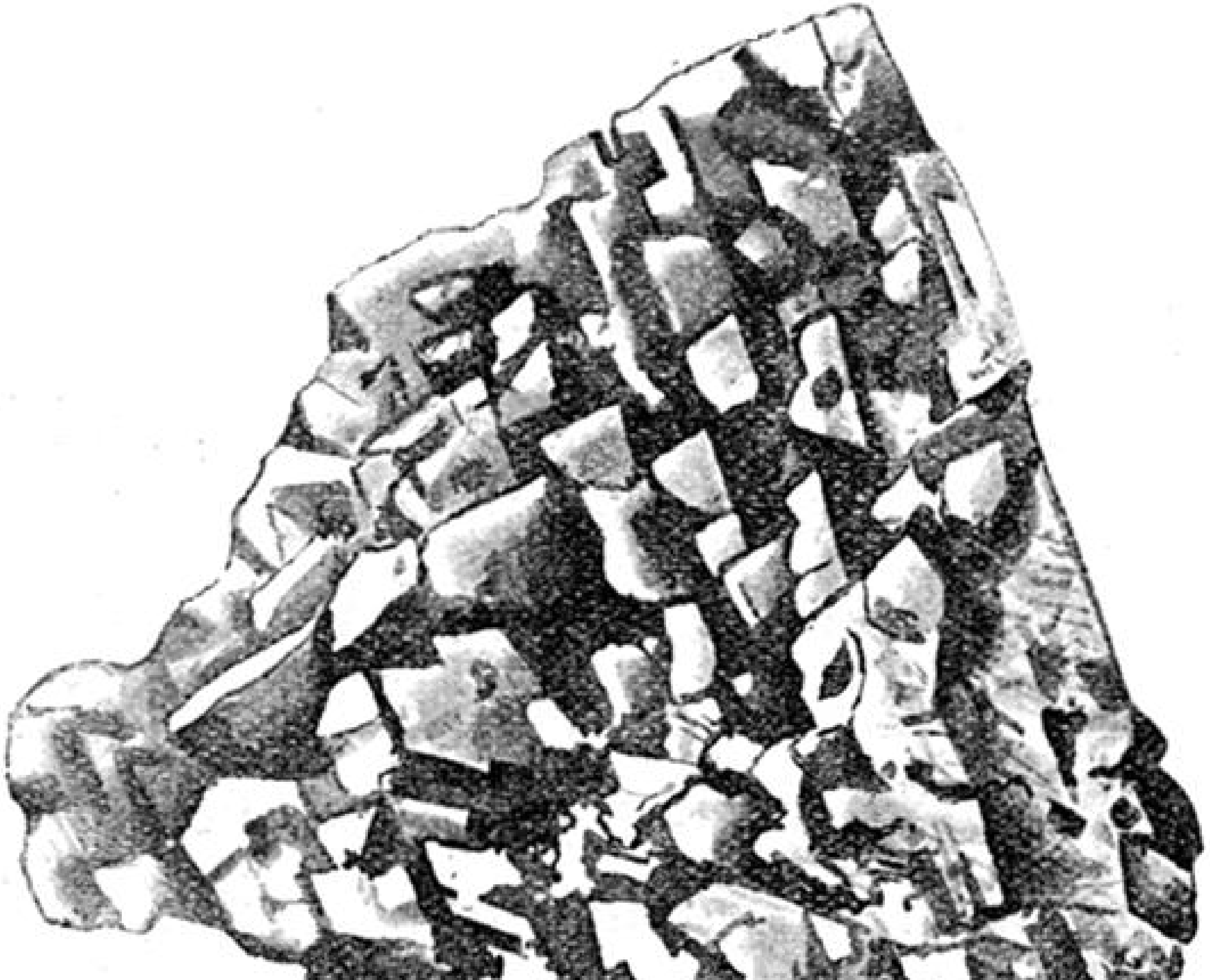
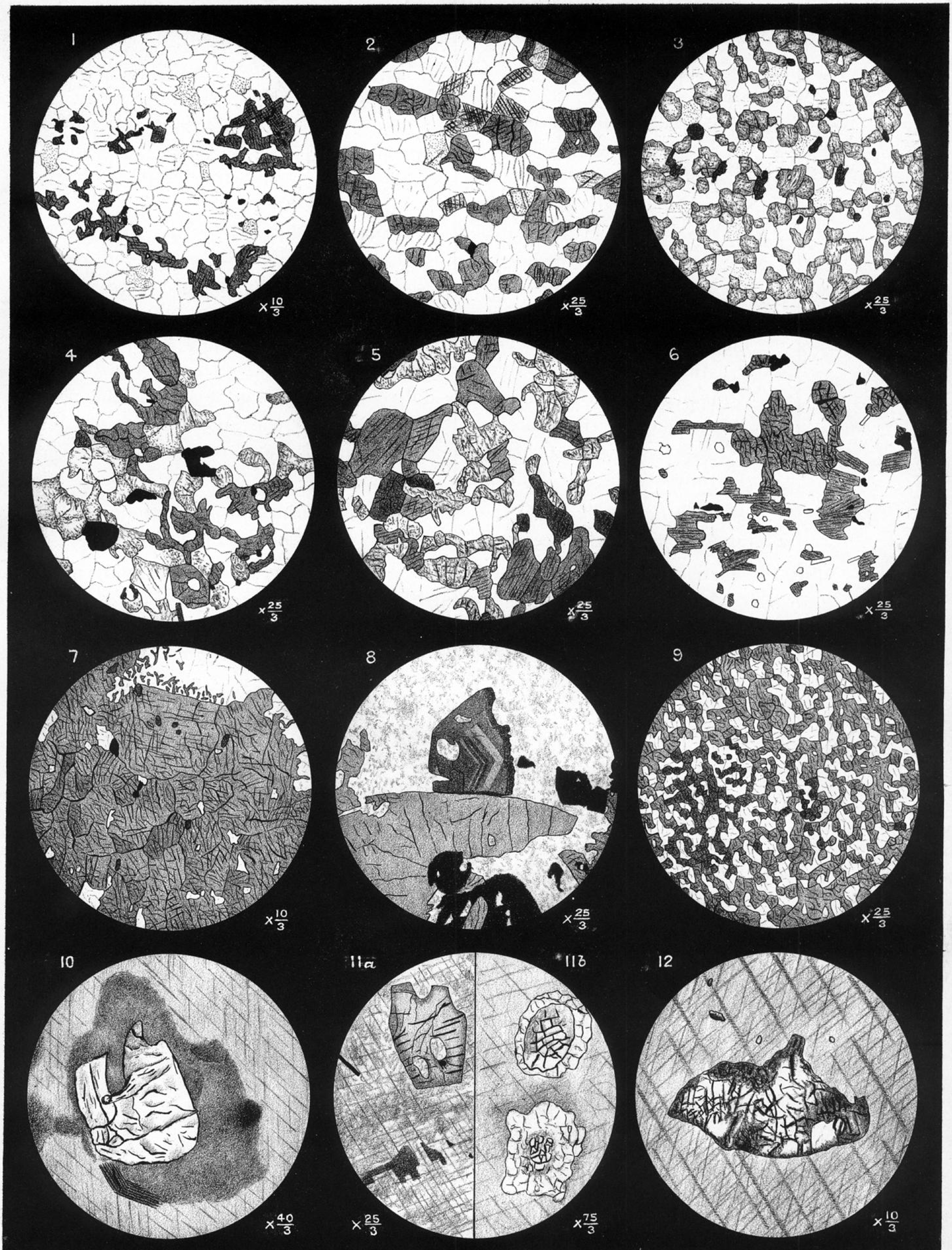


Fig. 22.





M.P.Parker del.et lith. West, Newman imp.